NASA Long Range Technology Goals

Volume II-A

Task 2 Report

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FOREWORD

This document is part of the Final Report performed under contract NASW-3864, titled "NASA Long Range Technology Goals."

The objectives of the effort were:

- To identify technologies whose development falls within NASA's capability and purview, and which have high potential for leapfrog advances in the national industrial posture in the 2005-2010 era.

- To define which of these technologies can also enable quantum jumps in the national space program.

- To assess mechanisms of interaction between NASA and industry constituencies for realizing the leapfrog technologies.

This Volume contains methodology used to assess the U.S. industrial sector and the first part of the findings pertaining to current U.S. industrial status.

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SOURCES:
U.S. DOC/BIE: U.S. Department of Commerce, Bureau of Industrial
U.S. DOL/BLS: U.S. Department of Labor, Bureau of Labor Statistics
U.S. DOC/BOC: U.S. Department of Commerce, Bureau of the Census
EOP/OMB: Executive Office of the President, Office of Management and Budget
U.S. CIA/DOI: U.S. Central Intelligence Agency, Directorate of Intelligence

A.0 INTRODUCTION

This Section details the approach and methodologies employed in this study to identify the advanced, innovative technologies that are needed to meet the nation's goals and aspirations in the early 21st century. The approach employed in this Study is illustrated in Figure 0-1. The Study examines two aspects: the technologies required to maintain a strong international economic posture; and the advanced technological capabilities that can contribute to fulfilling aspirations in other than economic areas, such as health, security, and pursuit of happiness.

With respect to economic goals, the study analyzes the major sections of the U.S. economy to establish the following factors:

- Current growth rates compared to historical growth patterns, and competitive posture vis-a-vis major foreign competitors;

- The reasons underlying unfavorable performance, e.g., flagging productivity;

- The degree to which long-term, innovative technologies might redress identified shortfalls.

A similar approach is taken with respect to the noneconomic goals, leading to the identification of new technologies that support national aspirations in these areas, e.g., advanced health-restoring techniques.

The second step of the method seeks to identify key long-term technologies which provide the capabilities to implement potential, advanced, future national space missions. The study applies criteria for characterizing the spectrum of missions with respect to their "utility" and derives the crucial, enabling technology drivers.

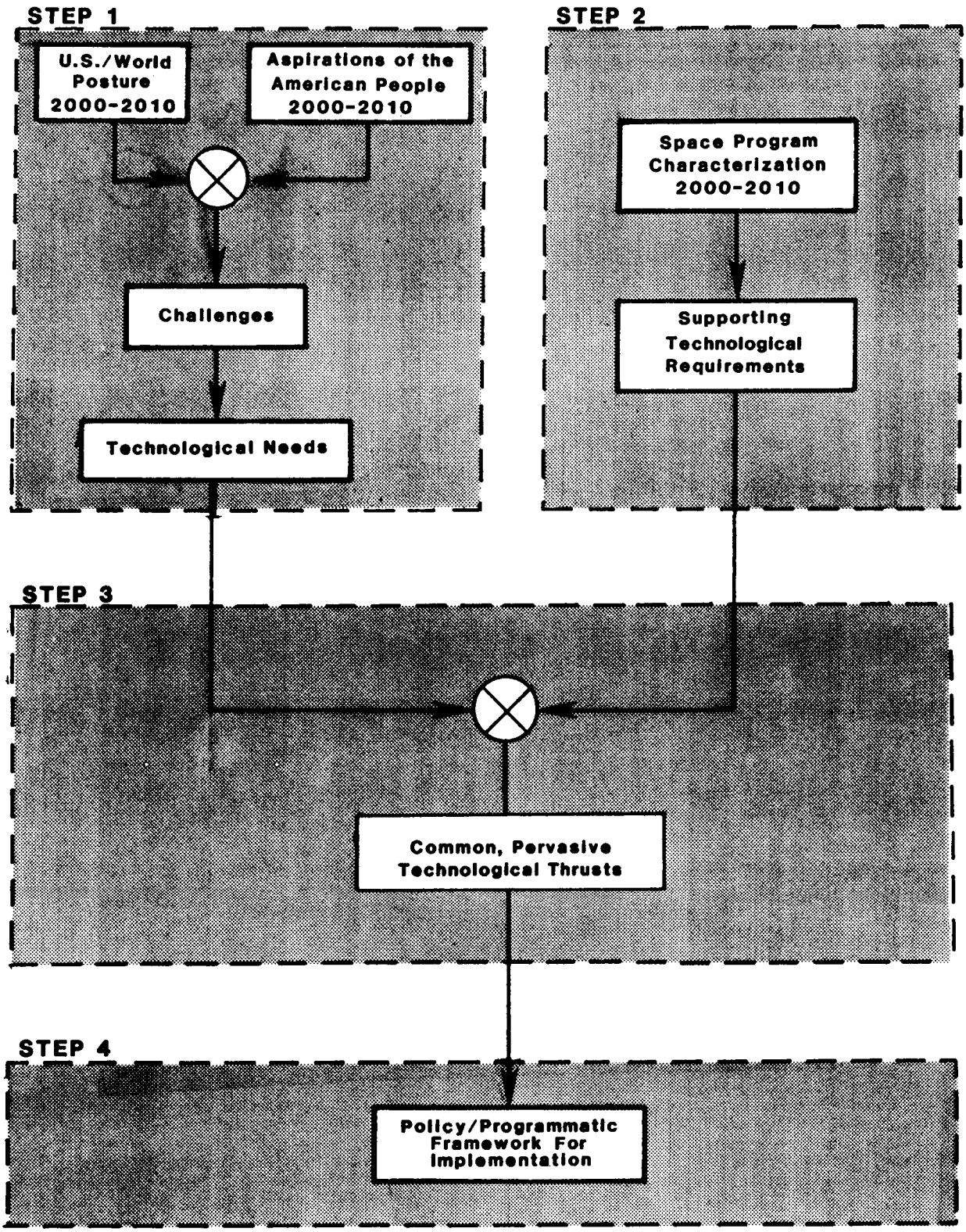

Figure 1-1. Study Approach

The third step compares the technologies identified in the first two steps and identifies common, underlying technological thrusts, i.e., areas of R&D that meet the needs of both industry and space program. These thrust areas represent directions in which application of NASA resources portends benefits that transcend the space program itself.

The fourth step examines mechanisms NASA might elect to adopt to structure its technology efforts in these thrust areas to maximize their contribution to both space and other national needs.

A.1 APPROACH TO ASSESSING U.S. VERSUS WORLD POSTURE IN THE EARLY TWENTY-FIRST CENTURY

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A.1 APPROACH TO ASSESSING U.S. VERSUS WORLD POSTURE IN THE EARLY TWENTY-FIRST CENTURY

A.1.0 BACKGROUND AND PURPOSE

This report intends to provide a factual, objective depiction of the socioeconomic posture of the U.S., as it exists now and as it can be reasonably extrapolated to evolve to in the 2000-2010 time frame.

Such a depiction is presented from two viewpoints, an external and an internal assessment. The external assessment compared the U.S. with the rest of the world; the internal assessment compared U.S. trends with respect to the U.S.'s own historical growth pattern.

The object of the external comparison is to assess whether the U.S. international leadership is, in fact, eroding. The internal comparison serves to gage whether or not the U.S. is indeed undergoing a historical "slowing down" process.

A.1.1 ASSUMPTIONS AND CRITIQUE

The assessments were performed by selecting and assigning values to the most significant socioeconomic indicators, chosen from the best available sources.

Not surprisingly, a review of the literature failed to yield a documented consensus as to which combination of indicators best depicts the posture of one society versus another. In general, while quantifiable indicators are reasonably well established in the economic area, they are more vague and more speculative in areas relating to societal structure and relationships: For example, how is one to quantify the masure of "quality of life?" This is due, in part, to the fact that the social sciences are more complex, and consequently, less exactly developed than economics.

Accordingly, the approach has been to select those economic and social indicators which enjoy the maximum degree of acceptance, and to subject them to stringent critique as to significance and applicability.

The projection of current national postures into the future presents particular challenges.

Breakthroughs cannot be forecasted. The advent of major disruptive or corrective events--such as global armed conflicts, social upheavals, or the achievement of a world union of nations portending universal peace--is highly speculative. In place of such speculations, the conservative position assumed here is that the socioeconomic evolution of the national and international posture of the U.S. and of the rest of the world will continue substantially at the present pace through the next two decades. As such, the projections developed and presented later in this report should be interpreted not as forecasts, but rather as indicators of "what would happen if historical trends were to continue as they are."

For purposes of international comparisons, it is of little meaning to compare the U.S. to the rest of the world taken as a whole. Such a comparison would show the U.S. at an overwhelming advantage, because most of the world's population is in the developing stage. Rather, we effected the comparison between the U.S. and countries and country groupings whose social structure and degree of development are closest to those of the U.S.

These countries and country groupings embrace free market economies and include:

- Japan
- The European Economic Community (EEC) as a whole

- Selected countries within the EEC; in particular France, the Federal Republic of Germany (FRG), Italy

For the internal comparisons, the historical time span examined ranges from 1950 to 1982. Shorter time periods, e.g., 1964-81, are used whenever earlier foreign data are unavailable or are of doubtful reliability.

A.1.2 DATABASES, DEFINITIONS AND LIMITATIONS

The data used for this study are drawn from the best available compilations. Table 1-1 depicts the principal categories of data utilized and their sources.

All statistical data have limitations, in particular when drawn from several countries. These limitations stem from two sources: methodology employed to gather the data, and level of accuracy of the data.

The principal limitations, and the methods adopted to reconcile the corresponding data, are summarized in the following discussion.

Equitable Comparison of National Economies

Conventional computations of National Accounts--gross national product (GNP) or gross domestic product (GDP)--are based upon the market prices effective within each country. Commonly used comparisons among countries are performed by converting GNP figures at prevailing rates of foreign exchange. However, exchange rates can be affected by factors other than just market prices--for example by the perceived stability and security of one currency vis-a-vis another, or by differing interest rates which attract or discourage short-term capital flows.

TABLE 1-1

PRINCIPAL CATEGORIES AND MAJOR SOURCES OF DATA

CATEGORY	SOURCES
ECONOMICS	● ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT ● UNITED NATIONS ● WORLD BANK ● CENTRAL INTELLIGENCE AGENCY
PRODUCTIVITY	● U.S. DEPARTMENT OF LABOR ● JOHN W. KENDRICK ● AMERICAN PRODUCTIVITY CENTER
INDUSTRIAL TECHNOLOGIES	● WORLD BANK ● BUREAU OF THE CENSUS ● U.S. DEPARTMENT OF LABOR ● NATIONAL SCIENCE FOUNDATION ● U.S. DEPARTMENT OF ENERGY
SPACE TECHNOLOGY	● NATIONAL AERONAUTICS AND SPACE ADMINISTRATION ● EUROPEAN SPACE AGENCY
DEMOGRAPHICS	● BUREAU OF THE CENSUS ● AGENCY FOR INTERNATIONAL DEVELOPMENT ● UNITED NATIONS
HEALTH	● WORLD HEALTH ORGANIZATION ● U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
ENVIRONMENT	● ENVIRONMENTAL PROTECTION AGENCY ● U.S. DEPARTMENT OF AGRICULTURE ● ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT ● U.S. COAST GUARD ● THE CONSERVATION FOUNDATION ● COUNCIL ON ENVIRONMENTAL QUALITY
CRIME	● FEDERAL BUREAU OF INVESTIGATION ● INTERNATIONAL POLICE ORGANIZATION (INTERPOL) ● U.S. DEPARTMENT OF JUSTICE
DISASTERS	● FEDERAL EMERGENCY MANAGEMENT AGENCY ● U.S. GEOLOGICAL SURVEY ● NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION ● SMITHSONIAN INSTITUTION ● AGENCY FOR INTERNATIONAL DEVELOPMENT
EDUCATION	● BUREAU OF THE CENSUS ● ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT ● NATIONAL SCIENCE FOUNDATION

Such a distortion is evidenced in ranking the U.S. GNP per capita with respect to the rest of the world. In 1980, the U.S. ranked ninth among developed nations: As of late 1984, it ranked first. Yet, the U.S. has not experienced unusual economic growth, nor have the other industrial nations experienced major decreases between 1980 and 1983. The apparent difference is due primarily to the recent dramatic strengthening of the U.S. dollar, see Table 1-2.

To mitigate this kind of distortion, several approaches have been taken to develop more sophisticated intercountry measures of GNP and GDP. Figure 1-1 illustrates how these several techniques affect the measurement of GDP, using the U.S. and Japan as examples.

The topmost curves--unadjusted GDP for the U.S.--provide a baseline expressed in current dollars. The second curve is the U.S. GDP adjusted to constant 1972 dollars to eliminate the effects of inflation. The third curve depicts the unadjusted GDP for Japan converted at current monetary exchange rates. The next curves show Japanese GDP adjusted to constant 1972 currency and constant 1972 dollars. Three approaches are given in these curves: the Kravis method (Ref. 1), the Purchasing Power Parity (Ref. 2) approach, and currency exchange. The Gilbert method (Ref. 3), which is not shown, produces results similar to that of Kravis and represents a similar degree of sophistication.

Figure 1-2 shows constant 1972 dollar comparisons for Germany, France and Italy (with Japan repeated for comparison purposes).

Note that whereas the absolute values of the respective GDPs differ by as much as 10 to 15% as a function of the method of comparison used, the slopes of the curves are essentially unchanged by the method employed. Since the truly significant elements are the slopes of the curves, the added complexity

TABLE 1-2

INDEX OF EXCHANGE RATES

COUNTRY	BASE YEAR 1981	INCREASE IN U.S. RATE OF EXCHANGE NOV. 1984
U.S.	1.00	1.00
JAPAN	1.00	1.11
ITALY	1.00	1.72
FRANCE	1.00	1.75
F.R. GERMANY	1.00	1.38

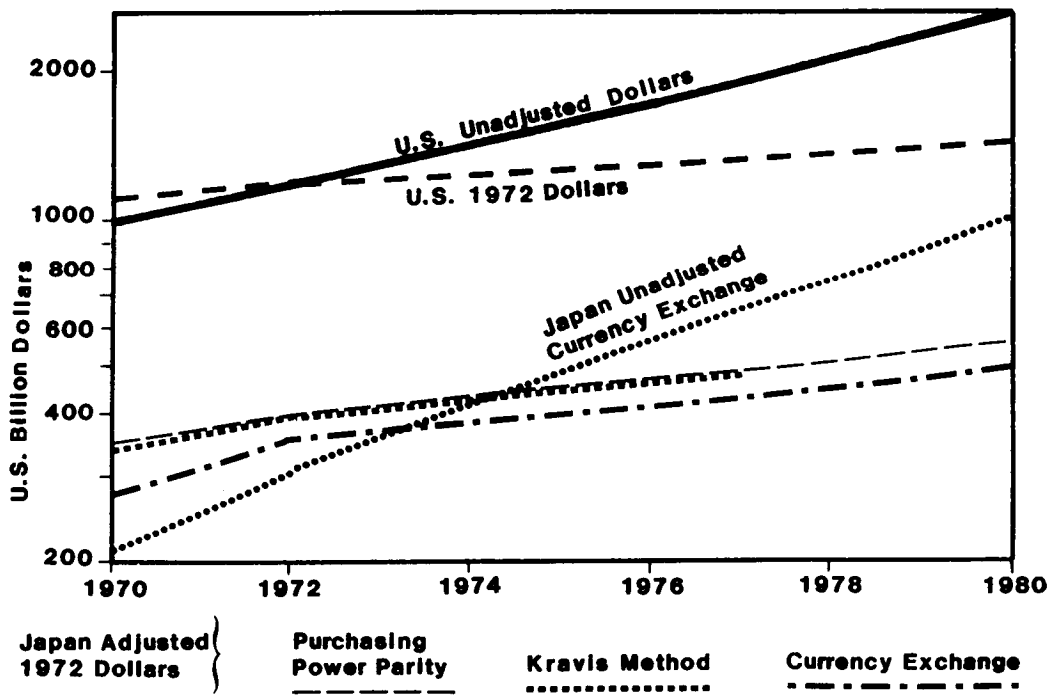


Figure 1-1. Total Gross Domestic Product Comparisons Between U.S. and Japan

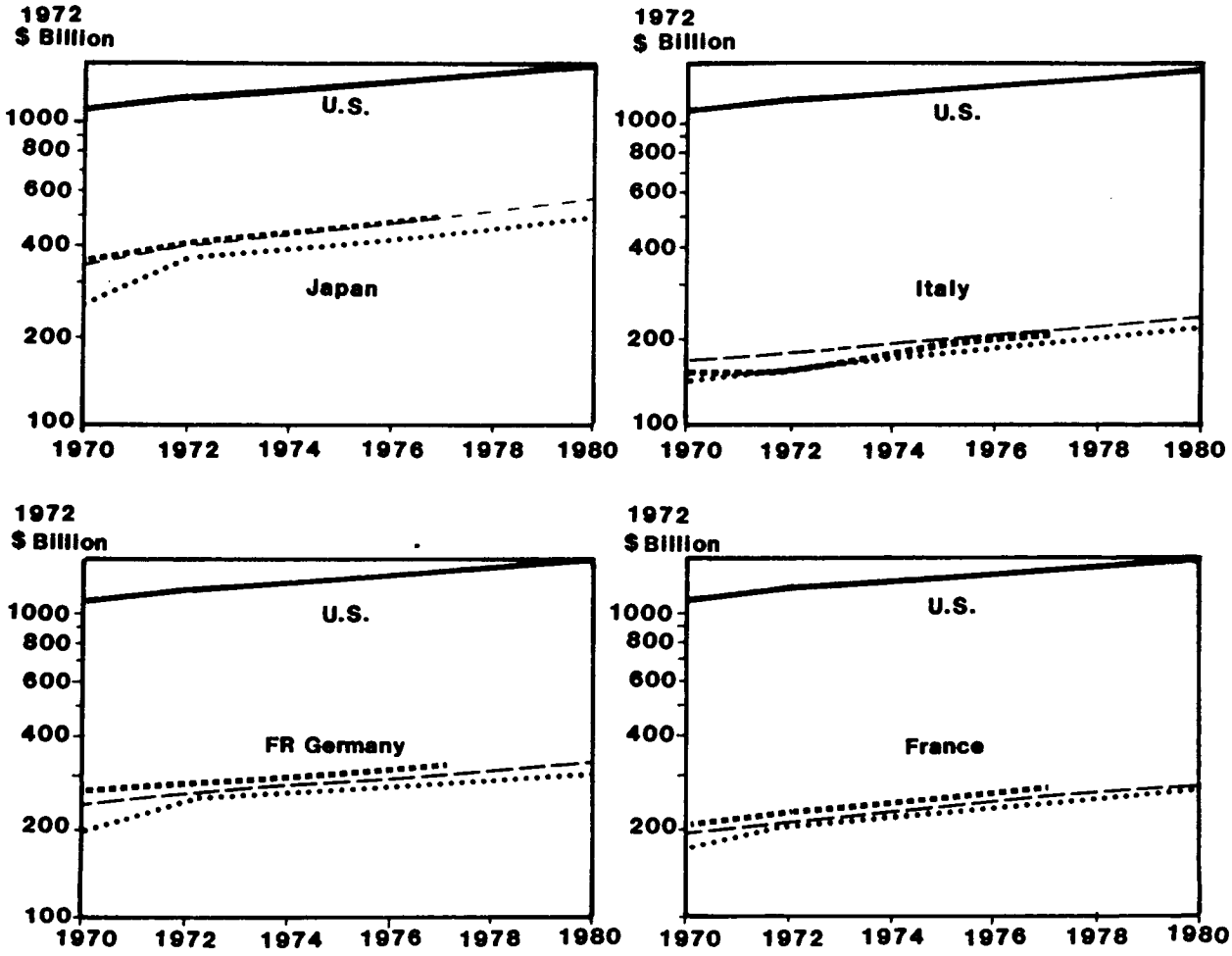


Figure 1-2. Total Gross Domestic Product Comparisons Between U.S. and Four Countries

involved in utilizing sophisticated methods does not appear warranted. The method employed in this study is thus to effect intercountry comparisons by reducing all economic data to 1972 dollars, at 1972 rates of exchange. The advantage is that the largest amount of available comparative data is available in this "72-72" format.

Comparable Measurements of Productivity

A source of apparent distortions derives from measurements of productivity, particularly as regards the "services" sector.

Numerous industries generate physical products, e.g., bushels of wheat, tons of steel. When divided by the number of man-hours used to produce them, these constitute a tangible measure of labor productivity. However, when these physical products are assigned specific dollar values based upon current market prices, intercountry comparisons of productivity become less certain. This is because market prices vary among countries; further, they can fluctuate due to causes which are exogenous to the productive sector.

Earliest economic concepts viewed productivity from an "agrarian" perspective: namely, as the ratio between goods produced (expressed in physical quantities, e.g., bushels of wheat, or in monetary terms, e.g., dollars collected) and the quantity of labor (e.g., man-hours) employed in producing them. This measure of productivity is still used currently as an indicator of a society's overall productive proficiency.

This agrarian-oriented concept eventually evolved to the recognition of the productive role of capital: inasmuch as the investment of capital provides the tools and facilities wherewith labor can operate productively.

As econometric techniques evolved further, it became apparent that year-to-year productivity changes (differential productivity) could not be fully accounted for through the sole contribution of the "tangible inputs" of labor and capital. During periods of economic growth, (e.g., the 1920s), an "excess productivity growth" was experienced--above and beyond the growth of tangible inputs. Originally (in the 1920s and 1930s), labeled "the area of our ignorance," the excess productivity was eventually (in the 1950s) ascribed to an intangible factor, variously designated as "know-how" or "technology input."

The modern view defines productivity as the outcome of several factors, principally: volume of applied labor, invested capital, and an excess productivity growth (above and beyond the rate contributed by capital and labor alone). Modern statistical techniques seek to quantify the contributions of factors which are responsible for the excess productivity growth, called partial factor productivity (PFP). As noted in Figure 1-3, productivity growth in PFP analysis is subdivided into know-how, training, effect of scale, demand, and other factors. When the yearly increase of tangible input (labor and capital) is added to excess productivity growth, the yearly growth in total output is obtained. Excess productivity growth in the period 1948-66 shows a 2.9% yearly increase. For the period 1966-76 several PFPs detracted from the excess productivity growth by approximately 1%, while the remaining factors contributed a positive growth, for the period, of 1.4%.

The PFP technique is a powerful tool for analysis of productivity growth. The Bureau of Labor Statistics (BLS) is currently compiling sectoral data for the U.S. Reliable PFPs are, as yet, unavailable for foreign countries.

Methods of Extrapolation

Long-term forecasts are difficult and often hazardous. This, however, does not appear to detract from numerous efforts

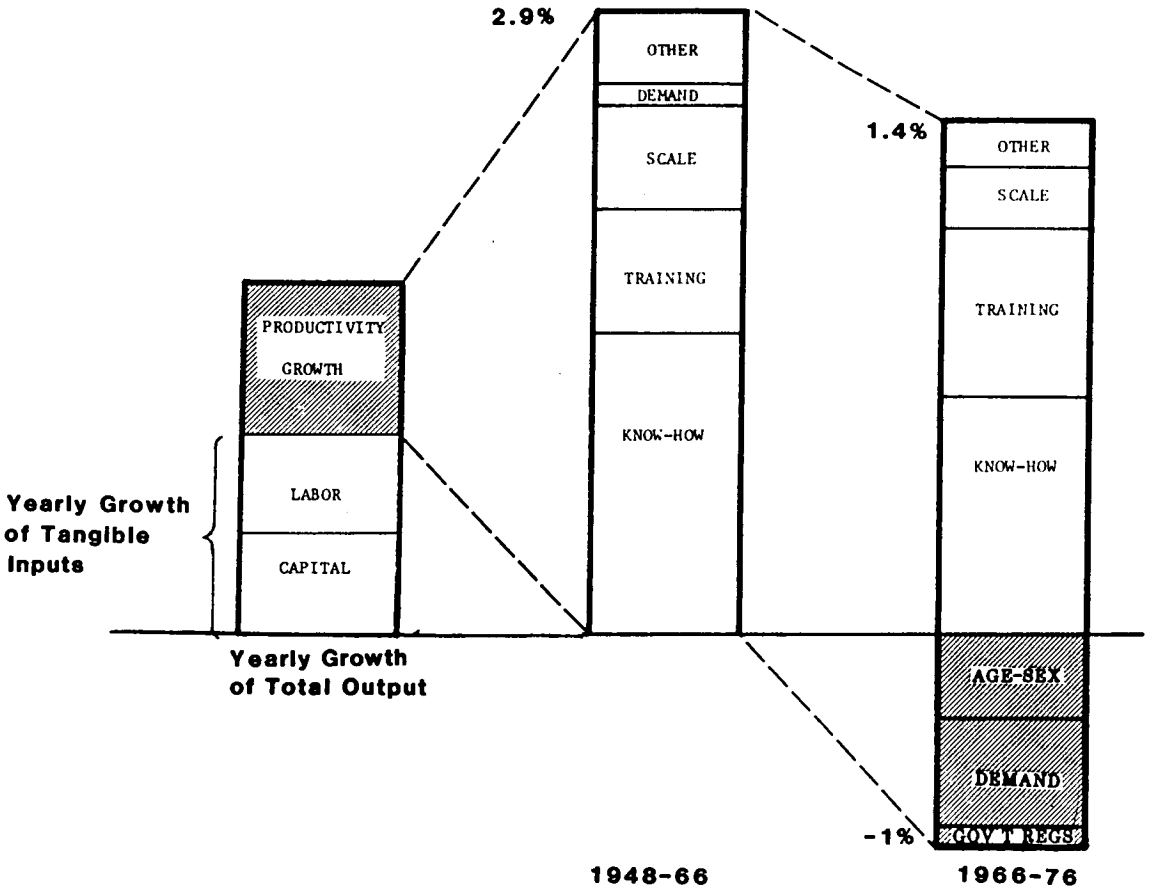


Figure 1-3. Factors of Productivity Growth U.S. Business Economy

to foresee the future, nor does it diminish the need to better understand what the future might bring in order to prepare for it, see Table 1-3. The need to develop a "reference" or "base-line" picture of the future is particularly important to gage the possible evolution of the U.S. economy over the next two or three decades, in the absence of an explicit national technology policy.

For the purpose at hand, we have analyzed the best available future extrapolation methodologies as represented by the models listed in Table 1-4. The number of available forecasts is quite numerous for the next one-to-ten years, but dwindles rapidly beyond the end of the next decade. The situation is worse for the countries which were selected for comparative purposes. Consequently, we have used available forecasts as far as they go. Beyond that, we have used a simple exponential (compound growth) extension of past trends of aggregate and sectoral gross product and productivity.

The long-term indicators resulting from our expotential extension should not be interpreted as forecasts, but merely as "indicators" of what would happen if the current growth rates of the countries being compared were maintained. The primary utility of our "indicators" is to identify those industries and sectors of the economy that are most vulnerable from intensifying international competitiveness, and which could therefore benefit most from a concerted national technology policy.

To examine the realism of our long-term "indicators," the BLS projections to 1995 were inspected. Over this time span, the BLS forecasts checked closely with our method of extrapolation.

The selected "indicators" of key economic performance (GNP growth rate and aggregate productivity) for the U.S. and for selected runner-up countries are provided in Chapter 2. It is worth re-emphasizing that our "indicators" are not forecasts or

TABLE 1-3

STATE-OF-THE-ART FORECASTING TECHNIQUES

UNCONDITIONAL	DETERMINES THAT CERTAIN EVENTS OR TRENDS WILL, IN ALL LIKELIHOOD, OCCUR IN THE FUTURE (THESE FORECASTS MIGHT MORE PROPERLY BE CALLED "PREDICTIONS").
CONDITIONAL OR PROBABILISTIC	ASSESSES THAT CERTAIN EVENTS OR TRENDS WILL OCCUR IN THE FUTURE WITH SOME PROBABILITY (NOT ALWAYS SPECIFIED), GIVEN CERTAIN LIMITING ASSUMPTIONS CONCERNING PRESENT AND FUTURE CONDITIONS AND POLICIES (UNDER A DIFFERENT SET OF ASSUMPTIONS CONCERNING CONDITIONS AND POLICY ACTIONS, DIFFERENT EVENTS OR TRENDS ARE LIKELY TO OCCUR).
EXPLORATORY	EXAMINES A WIDER RANGE OF TRENDS AND POLICIES IN AN OPEN-ENDED EXPLORATION OF POSSIBLE FUTURE DEVELOPMENTS, WITHOUT MUCH EMPHASIS ON THE PLAUSIBILITY OF THE UNDERLYING ASSUMPTIONS, RESULTING FUTURE TRENDS, OR SCENARIOS.
PRESCRIPTIVE OR NORMATIVE	IDENTIFIES, DETERMINES, AND ASSESSES THE EVENTS OR TRENDS THAT SHOULD (OR SHOULD NOT) HAPPEN AND DETERMINES THE POLICIES AND CONDITIONS THAT WILL LEAD TO THE DESIRED OUTCOME.

TABLE 1-4

CURRENT STATE-OF-THE-ART FORECAST MODELS

MODEL	TYPE	DEVELOPER	DESCRIPTION
WORLD 3 "LIMITS TO GROWTH"	CONDITIONAL OR PROBABILISTIC	MIT USING FORRESTER'S SYSTEMS DYNAMICS	DESCRIBES GLOBAL SYSTEM IN TERMS OF POPULATION, NATURAL RESOURCES, CAPITAL, AGRICULTURE, AND POLLUTION. INCORPORATION OF "FEEDBACK" RELATIONSHIPS AMONG THESE VARIABLES.
WORLD INTEGRATED MODEL (WIM)	CONDITIONAL OR PROBABILISTIC	M. MESAROVIC (CASE WESTERN RESERVE U.) AND E. PASTEL (TECHNICAL U., W. GERMANY)	BASED ON MESAROVIC'S MULTILEVEL HIERARCHICAL SYSTEMS THEORY THAT VIEWS WORLD IN TERMS OF ENVIRONMENT, TECHNOLOGY, ECONOMY-DEMOGRAPHY, GROUP, AND INDIVIDUAL. A SPECIALLY TAILORED WIM CURRENTLY MAINTAINED BY DOD.
LATIN AMERICAN WORLD MODEL (LAWM)	PRESCRIPTIVE OR NORMATIVE	FUNDACION BARILOCHE, ARGENTINA; INT'L DEVEL. RES. CENTER, O'HAWA; AND INT'L LABOR OFFICE	OPERATES THROUGH OPTIMIZATION PROCEDURES (i.e., ALLOCATES LABOR AND CAPITAL TO FOOD, HOUSING, EDUCATION, CAPITAL GOODS, AND OTHER GOODS AND SERVICES, TO MAXIMIZE LIFE EXPECTANCY AT BIRTH, THE BEST INDICATOR OF GENERAL LIVING CONDITIONS.
UN INPUT-OUTPUT WORLD MODEL "THE FUTURE OF THE	CONDITIONAL OR PROBABILISTIC; ELEMENTS OF	W. LEONTIEF AT UN	CONSISTS OF A 15-REGION INPUT-OUTPUT (45-SECTOR) MODEL OF THE WORLD ECONOMY INCORPORATING ENVIRONMENTAL RELATIONSHIPS. MODELS EQUATIONS SOLVED SIMULTANEOUSLY, USUALLY AT 5-YEAR INTERVALS FOR 1980, 1990, AND 2000.
GLOBAL 2000	COMBINATION OF OF ALL TYPES	INTERAGENCY TASK FORCE U.S. GOVERNMENT	COLLECTION OF SECTORAL MODELS INDEPENDENTLY DEVELOPED OR ADOPTED BY VARIOUS FEDERAL AGENCIES AND OTHER ORGANIZATIONS TO IDENTIFY FUTURE GLOBAL PROBLEMS AND TO STRENGTHEN THE GOVERNMENT'S CAPABILITY FOR LONG-TERM PLANNING AND ANALYSIS.
INFORUM AND LARGE ECONOMETRIC FORECASTING MODELS SUCH AS DATA RESOURCES INC., CHASE ECONOMETRICS	CONDITIONAL OR PROBABILISTIC	U. OF MARYLAND-ORIGINAL PROTOTYPE	COMPUTER-BASED INTEGRATED ECONOMETRIC AND INPUT-OUTPUT OTHER (MULTISECTORAL) MODELS FOR U.S. AND SELECTED OTHER COUNTRIES THAT GENERATE ENDOGENOUS FORECASTS GIVEN EXOGENOUS FORECASTS OF VARIABLES SUCH AS POPULATION GROWTH RATE, WORLD ENERGY PRICES ETC.
BACHE MODEL	CONDITIONAL OR PROBABILISTIC	BUREAU OF LABOR STATISTICS DEPARTMENT OF LABOR	COMPUTER-BASED MULTI-EQUATION MULTI-INPUT-OUTPUT MODEL FOR U.S.--USED TO ESTIMATE FUTURE EMPLOYMENT.

projections; rather, they represent plausible, future trends which may occur in the absence of a major technology initiative to improve U.S. industrial innovation, productivity, and international competitiveness.

Table 1-5 summarizes the principal limitations encountered in the data, and the methods we used to circumvent or alleviate their effects.

A.1.3 SELECTION OF INDICATORS

The assessment of the socioeconomic posture (status) and progress (trends) of a country, for comparison among countries, requires some form of succinct composite picture of sets of phenomena. For example, GDP represents a measure of the total goods and services produced by a country during a given period of time--generally annually. Such a measure is quantitative and is generally accepted: 1) as an indicator of the current economic "strength" of a nation; 2) as instrumental in gaging a nation's economic trend (by measuring the change in GDP with time); and 3) as providing a measure of the efficiency of application of resources--for example, by dividing GDP by the population, one obtains GDP per capita which indicates the "average" economic status of individuals of each nation.

Economists note that the use of "average" or per capita assessments may be inadequate to depict the true socioeconomic posture of a society. For example, one obtains the same GNP per capita whether the total national income is concentrated in a few individuals, or distributed evenly throughout the population. Thus, to more precisely represent this socioeconomic measure, indicators of "equity of distribution" are used.

Our study has chosen a set of indicators conditioned by the following factors: 1) the efficiency of description, discussed earlier; 2) the availability of unambiguous statistical data; 3) the cogency to U.S. national goals.

TABLE 1-5

DATA RECONCILIATION PROCEDURES

CATEGORY	LIMITATION	NORMALIZTION METHODS
INTERNATIONAL ECONOMIC COMPARISONS	MOST AVAILABLE DATA ARE BASED ON CONVERTING NATIONAL INDICATORS AT A GIVEN YEAR'S RATE OF EXCHANGE. THIS PRODUCES SIGNIFICANT FLUCTUATIONS BETWEEN "STRONG" & "WEAK DOLLAR" YEARS. FURTHUR, IT DOES NOT ADEQUATELY REFLECT THE DIFFERING INTERNAL PRICE INDICES.	COMPARE CONVENTIONAL HISTORICAL STATISTICS WITH STATISTICAL SERIES DERIVED BY USE OF GILBERT, KRAVIS OR EQUIVALENT METHODS.
MEASUREMENTS OF PRODUCTIVITY FOR SERVICES	IN COMPUTING PRODUCTIVITY, PHYSICAL PRODUCTS ARE ASSIGNED SPECIFIC DOLLAR VALUES BASED ON MARKET PRICES. IN MOST SERVICES, PRODUCTS ARE DIFFICULT TO QUANTIFY, ESPECIALLY IN TERMS OF ADDED VALUE FOR QUALITY.	SEGMENT PRODUCTIVITY INTO PARTIAL FACTOR PRODUCTIVITY; DEVISE MEASURES FOR QUALITY (UNDER RESEARCH).
METHODS OF EXTRAPOLATION	LONG-TERM FORECASTS DIFFICULT, OFTEN HAZARDOUS. RELIABILITY OF TECHNIQUES REDUCES SIGNIFICANTLY FOR FORECASTS BEYOND 10 YEARS.	REPLACE FORECASTING BY EXTRAPOLATION FROM HISTORICAL TRENDS. DO NOT LOOK UPON AS FORECASTS, MERELY "INDICATORS."
USE OF DEFLATORS	SOME SUBSECTORS UNDERGO INFLATION RATES SIGNIFICANTLY DIFFERENT (GENERALLY HIGHER) THAN THE OVERALL ECONOMY.	DEFLATE ABNORMAL SUBSECTORS USING SUBSECTOR DEFLATORS.
STATISTICS ON HEALTH, ENVIRONMENT, CRIMES	NOT STRICTLY COMPARABLE DUE TO DIFFERENCIES IN REPORTING BY VARIOUS COUNTRIES.	USE UNIFIED INTERNATIONAL CRITERIA; QUALIFY COUNTRIES AND DATA WHICH ARE NOT STRICTLY COMPARABLE.

As the analysis progressed, it was recognized that the statistical reliability of the diverse databases available and the variations of these database's definitions required that trend analysis, coupled with cautious interpretation, should be utilized rather than attempting an overly precise interpretation of the absolute values of the chosen indicators.

Figures 1-4 and 1-5 indicate the historical trends in gross domestic product and gross domestic product per employee (labor productivity) for major U.S. competitors (in 1972 $ and exchange rates). When the growth of GNP per employee of other nations is compared with the U.S., Figure 1-4, two salient points are apparent:

a) U.S. gross domestic product per employee (productivity, expressed in dollar value) is essentially flat, indicating a slow growth; and

b) The domestic product per employee (productivity) for comparable nations is growing faster and trends towards overtaking the U.S.

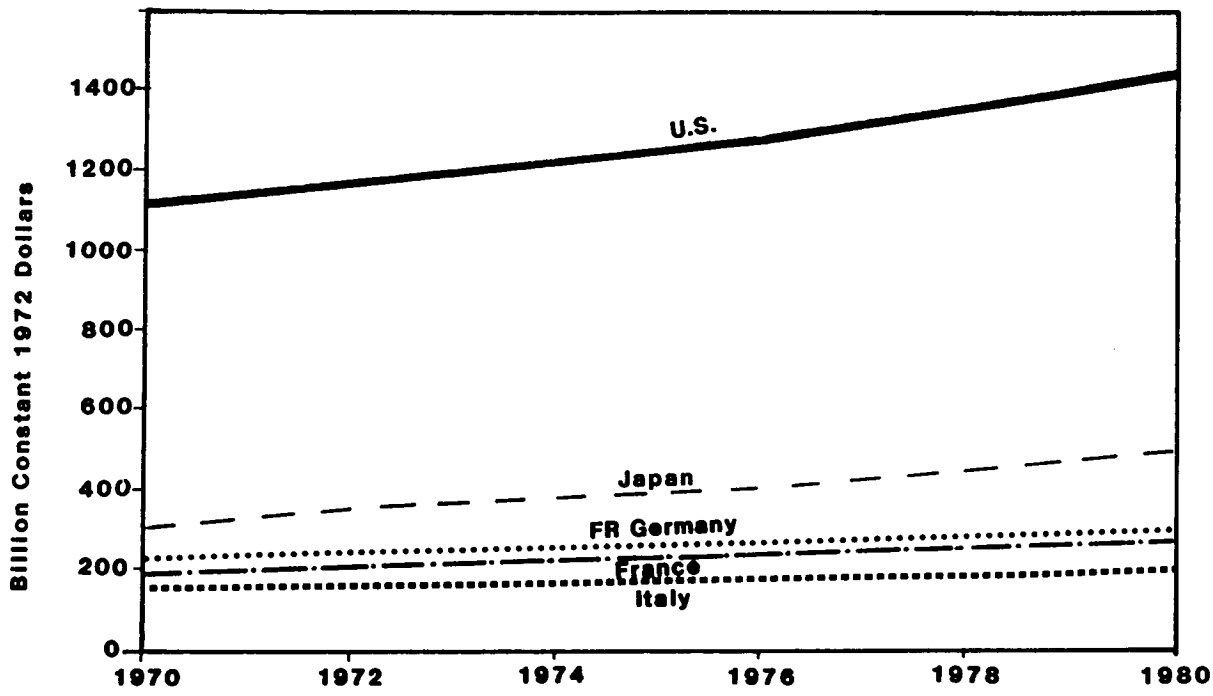
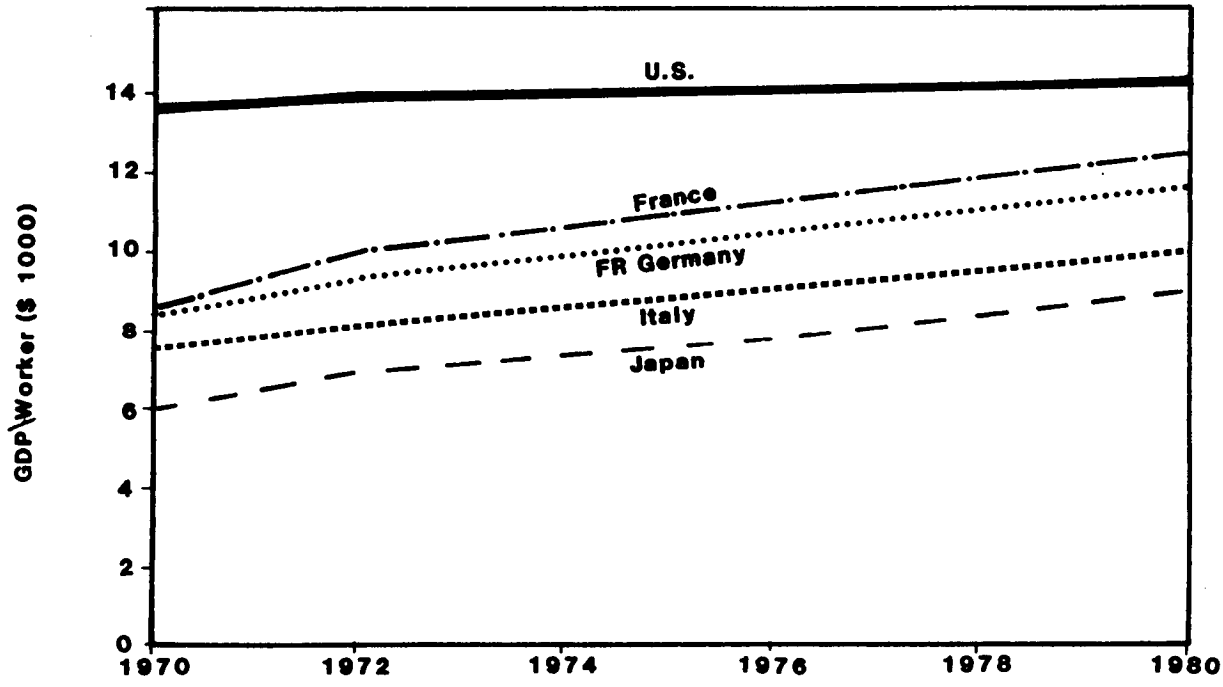


Figure 1-5. Total Gross Domestic Product



1972 dollars, 1972 rate of exchange

Figure 1-6. Total Productivity

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A.2 A CRITICAL REVIEW OF METHODOLOGICAL APPROACHES TO THE MEASUREMENT OF PRODUCTIVITY

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A.2 A CRITICAL REVIEW OF METHODOLOGICAL APPROACHES TO THE MEASUREMENT OF PRODUCTIVITY

A.2.0 PREAMBLE

Productivity measures the relationship between outputs (the quantity of goods and services produced) and inputs (quantities of labor, capital, energy, material resources). When the same amount of input produces a larger quantity of goods and services than before or when the same amount of output is produced with smaller quantities of inputs, productivity has increased. This Section reviews major historical developments in the field of productivity, defines major productivity technical concepts, and gives a detailed technical evaluation of the alternative methods used to measure productivity. In addition, we discuss the problems of and approaches to measuring productivity in the service sector. The reader may omit the technical discussion and still grasp the intent of this Section by reading the introductory paragraphs to each subsection and the general conclusion.

A.2.1 INTRODUCTION

Steady productivity growth is critical to continued U.S. economic progress and higher standards of living in the future, by contributing to enhanced U.S. international competitiveness, improved trade balance, reduced inflation, creation of new jobs, greater leisure time, better support for an aging population, and even improved environmental quality. Central, in turn, to sustained productivity growth is technological progress since, without technological progress, industry creates fewer jobs, the nation's capital stock becomes obsolete, productivity stagnates, inflation becomes difficult to control, and the nation's international competitiveness suffers.

Our attention as a nation, therefore, must be focused on productivity: What it is, how it is measured, and how it can be

improved in the future. This paper presents a critical review of the measurement of productivity, in an effort to help elucidate key underlying concepts, important relationships, and major methodological approaches.

A.2.2 PRODUCTIVITY SLOWDOWN: REVIEW OF MAJOR RECENT DEVELOPMENTS

Before a technical discussion of productivity, it is instructive to highlight its importance by reviewing a few recent productivity-related developments that have affected the viability of the U.S. economy. These developments, which pertain to the significant slowdown in U.S. productivity growth during the past decade, can be summarized as follows:

1. The U.S. has suffered a serious deterioration in its international economic competitiveness during the past two decades, as evinced by the pervasive secular erosion in the share of world markets across a wide spectrum of manufactured products, including steel, automobiles, and consumer electronics. This has meant not only diminishing U.S. export shares internationally--although U.S. exports have been rising in the aggregate in absolute terms--but also a dramatic reduction in the share of U.S. industries in domestic markets where foreign producers have established an increasingly strong position in recent years.

2. At a more fundamental level, however, the long-term deterioration in U.S. international competitiveness has been closely linked with a serious slowdown in the growth of U.S. industrial productivity, as well as innovation, since the late 1960s. Over the past decade, the U.S. has experienced a slower growth in productivity compared with other major industrialized countries. Although the U.S. has not been alone in

suffering a decline in productivity growth and, in fact, still occupies a leading position in terms of productivity **levels**, the deceleration in the productivity growth rate has been serious.

3. The causes of the U.S. productivity slowdown have been investigated extensively in recent years. Among the most important reasons cited for the slowdown in U.S. productivity growth are the following:

- Demographic shifts affecting the labor force, as reflected by the increase in the proportion of less-skilled youths and women in the labor force;

- A slowdown in capital investment, as reflected by the reduction in the rate of growth of the capital-labor ratio;

- The reduction in the rate of increase of intangible capital (expanded knowledge base) as reflected in part by the decrease in the proportion of GDP allocated to R&D during the late 1960s and 1970s;

- Increased government regulation--e.g., environmental, health and safety regulations--resulting in both increased direct costs of compliance and uncertainty discouraging new investment and efficiency;

- Growing alienation of workers and deteriorating labor/management relations;

- The shift of national output toward services, away from the production of goods.

These causal factors are difficult to sort out and are further complicated by contributing factors and developments, such as high energy prices, high interest rates and high cost of capital, overseas investments by U.S. multinational companies seeking proximity to international markets, lower labor and production costs, and/or relief from government regulations at home.

From a national policy perspective, the point should be underscored that one of the most important new realities of the 1980s is the increasingly critical nature of the relationship between productivity and competitiveness. Over the next two decades the American economy will undergo a technological transformation, as new and advanced technologies will continue to be adopted by the nation's industry at an accelerating pace to improve productivity and enhance international competitiveness. This transformation has already started with extensive modernization efforts in such traditional industries as automobiles, machine tools, and textiles, as part of a broad process of structural change and readjustment in response to both increasing international competition and domestic factors and developments.

Over the long run, by far the most important source of productivity growth is the advance in technological knowledge embodied in new product and process innovations. Capital investment is therefore an important ingredient in productivity growth, as well as long-term science, technology, and R&D policies designed to stimulate steady growth in innovation. Investment in human capital, including not only formal education but also the lifelong training and retraining of workers, is also of the utmost importance.

A.2.3 PRODUCTIVITY: DEFINITION AND MAJOR CONCEPTS

The pertinent literature on the overall subject is voluminous, growing rapidly, and quite technical. Any one particular aspect of the overall problem of productivity measurement, either

conceptual or empirical, can easily be the subject of extensive discussion. This discussion will, therefore, emphasize major concepts, methods and relationships.

Productivity is a measure of the productive efficiency with which resources are transformed into goods and services. Thus, productivity generally refers to the success at combining various inputs to produce a given level of output at minimum cost. Consequently, the measurement of productivity requires an analysis of the relationship between outputs (i.e., the quantity of goods and services produced) and inputs (i.e., quantities of capital, labor, energy, material resources).

In its simplest form, productivity is quantified by a ratio of output to input, both measured in physical units:

$$A_L = \frac{Q}{L} \qquad A_K = \frac{Q}{K} \tag{1}$$

where A_L and A_K refer to the productivity index for labor and capital, Q is the level of output, and L and K are, respectively, the labor and capital resources used. These are partial productivity indices.

Among these partial productivity measures perhaps the most commonly used is labor productivity. The U.S. Bureau of Labor Statistics (BLS), for instance, has regularly compiled and published measures of labor productivity. The BLS computes an index of output per employee hour by dividing an output index by an index of aggregate employee hours. For most industries, measures are prepared separately relating output to a) all employee hours, b) production worker hours, and c) nonproduction worker hours. For these measures, the standard definition of production workers and nonproduction workers are used. Output per man-hour refers to the constant dollar value of goods and services produced in relation to the man-hours of all persons employed (including proprietors and unpaid family workers). Corresponding and com-

parable indexes of hourly compensation and unit labor costs are also developed.

Such partial productivity measures may be useful for measuring the savings from the usage of particular inputs achieved over time. However, they suffer from serious conceptual shortcomings and fail to provide a reliable measure of overall changes in productive efficiency. Computing a family of such indices or developing an aggregate, composite index by somehow weighting two or more of such indices will, of course, do nothing to overcome the fundamental shortcomings of partial productivity measures. The basic, and rather obvious, problem here is that increases in such measures may simply reflect the substitution of one input for another. For instance, increases in labor productivity may well be due to substitution of capital for labor, while output remains constant.

In contrast, the total factor productivity (TFP) methodology, developed to overcome the basic deficiencies of the partial productivity indices, is intended as a more comprehensive measure of productivity, relating output to **all** associated inputs. Consequently, total factor productivity can be thought of as a measure of the aggregate productive efficiency of all of the factor inputs taken together. TFP is also known as "multifactor productivity."

The TFP methodology, developed and progressively refined by economists over the past several decades, represents the main analytical framework for measuring productivity. The roots of total factor productivity go back to the works of Tinbergen (Ref. 1), Stigler (Ref. 2), Solow (Ref. 11), Kendrick (Ref. 3), and Denison (Ref. 4), and has been further refined by Jorgenson and several collaborators--Griliches (Ref. 6, 7, 8), Christensen (Ref. 9), and Gollop (Ref. 10).

The driving idea behind the total factor productivity concept is the notion of measuring in real terms the difference or "residual" between the observed rate of change in output and the observed rate of change in the associated factor inputs, both appropriately quantified and weighted. It is this "residual" that presumably cannot be explained by the changes in the usage of factor inputs. This is why total factor productivity is often referred to as the "residual," or has been called a measure of the "unexplained residual."

Without too much exaggeration, the intellectual origin of these concepts (i.e., total factor productivity, the residual) can be traced to the major finding by economists in the late 1950s and 1960s that the growth of output experienced in the U.S. historically has been significantly greater than can be reasonably ascribed to input growth. This basic finding was foreshadowed by the earlier findings in the 1920s, based mostly upon partial productivity measures, that noted that the conventionally measured inputs, capital and labor, leave a large portion of the growth of output unexplained.

Over the past three decades, many researchers have attempted to narrow down the size of the residual through the development of progressively more and more refined techniques capable of analyzing an increasing number of factors contributing to the growth of output and the dynamic interaction among these factors.

Broadly speaking, a central question in measuring productivity has been whether and how well the pertinent factors are in fact taken into account in developing total factor productivity measures, so that the "residual" correctly identifies and quantifies "true" changes in productivity.

A.2.4 ALTERNATIVE METHODS OF MEASUREMENT

A change in total factor productivity is usally interpreted as: 1) the rate of change of an index of outputs divided by an

index of inputs (Ref. 6); or 2) a rate of shift in a production function (Ref. 1), where a production function denotes the relation between quantities of different types of inputs used and the quantities of different types of outputs produced in a given period.

The first, which can be called the "index number" approach to TFP measurement, represents the more traditional or conventional approach and has a certain computational simplicity. The second, which might be called the "production function" approach, represents the main-line theoretical approach to productivity measurement.

Recent developments in microeconomic theory focusing on the duality of the production and cost structure of firms have made it possible to evaluate the production structure of firms via an analysis of their cost structure, through the specification and empirical estimation of econometric cost functions. This econometric cost function approach is particularly useful in situations characterized by the presence of multiple outputs, common and joint costs, economies of scale and scope, factor substitution among various factor inputs, and other features (e.g., the underlying production technology, operating characteristics and related qualitative features of the firm are significant determinants of overall performance).

Index Number Approach

Most of the attempts at measuring total factor productivity have used some variant of the following formula:

$$A = \frac{\sum_{i=1}^{m} v_i y_i}{\sum_{i=1}^{n} w_j x_j} \qquad (2)$$

where

A = is the total factor productivity index;

y_i = is output (quantity of the ith type of product or service, i=1, 2, ..., m (e.g., residential, commercial, industrial and other sales of electricity);

x_j = is quantity of the jth type of input, j-1, 2, ..., n;

v_i = is weighting factor for the ith type of output;

w_j = is weighting factor for the jth type of input.

The rate of change of total factor productivity may be expressed as:

$$\frac{\Delta A}{A} = \frac{\Delta Y}{Y} - \frac{\Delta X}{X} \quad \text{or} \quad \frac{dA}{A} = \frac{dY}{Y} - \frac{dX}{X} \tag{3}$$

where ΔA, ΔY, and ΔX refer to discrete changes (e.g., between two consecutive years); dA, dY, and dX refer to continuous changes; and Y and X refer to aggregate output and input measures.

An alternative way of expressing the rate of change in total factor productivity is as follows (Ref. 4):

$$\frac{\Delta A}{A} = \frac{Y_t/Y_o}{X_t/X_o} - 1 \tag{4}$$

Earlier efforts to quantify total factor productivity used a Laspeyres weighting system for the construction of aggregate output and input measures (i.e., v_i and w_j, respectively), that requires the assumption of constant base-period product and factor input prices and, therefore, constant base-period revenue and cost shares.

The Laspeyres index has a certain practical appeal, because of its computational simplicity. It also has an intuitive appeal, in that all variations in the resulting TFP index are presumed to be due to variations in both output and input quanti-

ties measured in physical terms. However, Diewert (Ref. 12) has shown that the Laspeyres index is not exact except under conditions of perfect input (or output) substitutability.

An alternative approach for measuring the relative growth rates of outputs and inputs is the Divisia index based on proportional rates of growth in total output and total input.

In measuring total factor productivity, the Divisia index, with the Tornqvist approximation, has been found to be preferable to the more restrictive Laspeyres index (or other, similar, indices, such as the Paasche index).

In summary, index number procedures represent production processes. It is therefore desirable to choose a procedure (e.g., the Divisia index) that is capable of representing a diversity of possible production structures (i.e., one which is free of a priori restrictions, such as constant returns to scale, separability of outputs and inputs, predetermined elasticities of substitution among factor inputs, homogeneity, etc.).

The Production Function Approach

The measurement of total factor productivity is based on the economic theory of production. Central to the theory of production is the concept of the production function. A production function is a mathematical function that relates the quantities of inputs and the quantities of outputs within a production unit (firm, industry, national economy). It is generally regarded as a technical relationship between the quantities of inputs and the maximum amount of output that can be produced with a given set of inputs. Hence, the accurate specification of the form and the econometric estimation of the parameters of the production function are crucial to the measurement of productivity.

Two well-known production functions, the Cobb-Douglas and the constant elasticity of substitution (CES) production functions will be briefly mentioned.

The general form of the Cobb-Douglas production function for two factors is:

$$Q = AL^{\alpha}L^{\beta} \tag{5}$$

where A, α and β are parameters. The value of A is usually taken to be a measure of the efficiency of the production process. If $\alpha + \beta = 1$, there are constant returns to scale and for $\alpha + \beta > 1$, there are increasing returns to scale. Notice that these are independent of the values of K and L and apply at any point on the production function.

The Cobb-Douglas production function is rather restrictive in that the elasticity of substitution is equal to 1 at every point on the function. A logical generalization is to allow the elasticity of substitution to be a constant and the sum of the elasticities to be different from 1. For two factors of production the general form of the CES production function is

$$Q = \gamma\left[(1 - \delta)K^{-\rho} + \delta L^{-\rho}\right]^{-\nu/\rho} \tag{6}$$

where γ, δ, ρ and ν are parameters. The value of the parameter γ is a measure of the efficiency of the process. For positive values of Q, K and L, the function is single-valued and continuous (subject to some restrictions on the values of the parameters).

The explicit consideration of production function as the basis for total factor productivity analysis was introduced by Solow (Ref. 11). The fundamental Solow approach to the measurement of total factor productivity can now be briefly described.

Consider the two-factor (i.e., capital and labor), twice differentiable production function:

$$Q = A(t)\ F(K,L) \tag{7}$$

where A(t) is a measure of autonomous and neutral technological change and the function F is homogeneous. Differentiating with respect to time and dividing by Q yields:

$$\frac{dQ}{Q} = \frac{dA}{A} + \left[\frac{dK\ F_K}{Q} \cdot \frac{dK}{K} + \frac{dL\ F_L}{Q} \cdot \frac{dL}{L}\right] \tag{8}$$

where F_K and F_L are partial derivates of output with respect to K and L and the variables preceded by d refer to time derivates of the variables of equation 7.

Suppose the production function in equation 7 is as shown in equation 5; then equation 8 reduces to:

$$\frac{dA}{A} = \frac{dQ}{Q} - \left[\alpha\ \frac{dK}{K} + \beta\ \frac{dL}{L}\right] \tag{9}$$

where $\beta = (1-\alpha)$; α and β are the shares of capital and labor; and dQ, dK, and dL are the time derivatives of Q, K, and L.

It should be noted that the parameters α and β, denoting the shares of capital and labor in total output, correspond to the input weights, w_j, given in equation 2 above.

The correspondence between the measurement of total factor productivity using the production function approach and the index number approach can be briefly illustrated by comparing these results with that obtained by Kendrick (Ref. 4).

Kendrick approaches the measurement of dA/A by using a distribution function (i.e., arithmetic weighting of capital and labor share in output). He implicitly assumes a homogeneous production function to obtain the following:

$$\frac{dA}{A} = \frac{Q_1/Q_o}{(wL_1 + rK_1)/(wL_0 + rK_0)} - 1 \qquad (10)$$

where w and r are the wage rate and the rate of return on capital respectively; variables with the subscript 1 refer to the current period; and variables with the subscript o refer to the base period. In empirical estimates, the weights in calculating equation 10 are often permitted to change smoothly over time (Ref. 13).

Under the assumption of competitive equilibrium the Kendrick measure of equation 10 can be stated as:

$$\frac{dA}{A} = \frac{Q_1/Q_o}{\alpha_o \frac{K_1}{K_o} + \beta_o \frac{L_1}{L_o}} - 1 \qquad (11)$$

This is equivalent to Solow's measure for small changes in the quantities of inputs and outputs (Ref. 11).

The magnitude and stability of the change in total factor productivity, dA/A, obtained through the production function approach, will depend on the form of the production function. Any errors due to mis-specification will find their way into the measure of dA/A. In addition, proper measurement of K and L and adjustment for their quality changes will prove important. Further, important variables other then K and L may be left out of the production function.

The traditional production function approaches (e.g., Cobb-Douglas, CES) are rather restrictive by imposing the assumptions, for instance, of constant returns to scale (Cobb-Douglas) and constant elasticity of substitution among various factor inputs (CES). In addition, assumptions of cost minimization, equilibrium in product and factor markets, perfect competition (e.g., factor prices and shares reflecting their marginal contribution, etc.) bring into question the reliability of total factor productivity results based on the production function approach.

Finally, conventional production function approaches, quite apart from the restrictions they impose, are generally found inadequate in analyzing the structure of production in cases characterized by multiple outputs and inputs, joint costs, scale and scope economies, and factor substitution among various inputs. These, among others, also happen to be key features of electric utilities.

Recent development in production theory, however, may help overcome some of the shortcomings of these traditional production function approaches to the measurement of total factor productivity. The translogarithmic (translog) cost (production) function approach, in particular, is very important to consider. The translog approach (for short), which belongs to a group of generalized or "flexible" functional forms (e.g., the generalized Leontief and generalized Cobb-Douglas functions), is described below as part of the discussion focusing on the econometric cost function approach to the measurement of total factor productivity.

The Econometric Cost Function Approach

Earlier empirical studies of a firm's production and cost structure, employing Cobb-Douglas or CES functional specifications or their variants, have generally assumed that production processes involve a single output produced by using aggregate capital and labor inputs. It is well-known that extensions of these traditional functional forms to cases involving multiple outputs and multiple inputs impose highly restrictive assumptions on substitution possibilities and the separability of costs.

A number of key theoretical and empirical developments over the past decade or so have made it possible to study the multiproduct production structure of firms via econometric techniques for modeling the structure of cost. A series of contributions has introduced "flexible" functional forms that place no prior

constraints on substitution elasticities and also permit the estimation of cost (production) function parameters with more than two inputs. In the most simple terms, the duality between production and cost functions can be viewed as a reflection of the fact that prior information on the firm's objective function and its associated maximizing behavior allows the identification of the underlying production function from an estimated cost (or profit) function. That is, the production and cost (or profit) functions for a given firm are simply equivalent representations of the firm's underlying production technology under the required assumptions of firm behavior (e.g., cost minimization).

The efficient transformation of a vector of inputs X into a vector of inputs Y can be represented by an implicit function:

$$f(y_1, y_2, \ldots, y_m; x_1, x_2, \ldots, x_n; T) = 0 \qquad (12)$$

where T is time, representing shifts in the function due to changes in productivity. The unique cost function which is dual to equation 12 can be written as:

$$C = g(y_1, y_2, \ldots, y_m; p_1, p_2, \ldots, p_n; T) \qquad (13)$$

where the p_j are the prices at which the x_js can be purchased and C is total cost:

$$C = \sum_{j=1}^{n} p_j x_j. \qquad (14)$$

The cost function of equation 13 reflects the technological constraints embodied in the underlying production process, provided the equation 13 can be interpreted as the minimum cost of producing $y_1, \ldots, y_m$, given input prices; of all the possible input combinations that could produce $y_1, \ldots, y_m$, the firm is considered to have chosen that input bundled with the lowest

cost. Correspondingly, the output levels $y_1, \ldots, y_m$ are to be interpreted as the maximum output levels, given input quantities $x_1, \ldots, x_n$.

The first partial derivatives of the cost function with respect to the p_js are equal to the cost-minimizing input levels. This convenient property of the cost function, known as Shephard's (Ref. 15) lemma, can be written as:

$$\frac{\partial C}{\partial p_j} = x_j \tag{15}$$

This result can be conveniently expressed in logarithmic form for the translog function (see below) as:

$$\frac{\partial \ell n\ C}{\partial \ell n\ p_j} = \frac{p_j x_j}{C} = s_j \tag{16}$$

where s_j indicates the cost share of the jth factor input.

The total derivative of the log of the cost function with respect to time yields:

$$\frac{d\ \ell n\ C}{dT} = \sum_{i=\ell}^{m} \frac{\partial \ell n\ g}{\partial \ell n\ y_i} \frac{d\ \ell n\ y_i}{dT} + \sum_{j=\ell}^{n} \frac{\partial \ell\ n\ g}{\partial \ell n\ p_j} \frac{d\ \ell n\ p_j}{dT} + \frac{\partial \ell n\ g}{\partial T} \tag{17}$$

The total derivative (d ℓn C/dT) can be interpreted as the rate of growth of total cost. The right-hand side of equation 17 shows how the rate of growth of cost can be allocated among changes in output levels, changes in factor prices, and shifts in the cost function (changes in productivity).

Total differentiation of equation 14 with respect to time yields:

$$\frac{d\ \ell n\ C}{dT} = \sum_{j=1}^{n} \frac{p_j x_j}{C} \frac{d\ \ell n\ p_j}{dT} + \frac{d\ \ell n\ x_j}{dT}$$

$$= \sum_{j=1}^{n} s_j \frac{d \ln p_j}{dT} + \sum_{j=1}^{n} s_j \frac{d \ln x_j}{dT} \qquad (18)$$

Equations 16 and 18 can be substituted into equation 17 to obtain:

$$- \frac{\partial \ln g}{\partial T} = \sum_{i=1}^{m} \frac{\partial \ln g}{\partial \ln y_i} \frac{d \ln y_i}{dT} - \sum_{j=1}^{n} s_j \frac{\ln x_j}{dT} . \qquad (19)$$

The $\partial \ln g / \partial \ln y_i$ are the cost elasticities of the respective outputs. These cost elasticities are equal to the shares of the outputs in total revenues.

$$r_i = \frac{p_i y_i}{\sum_{i=1}^{m} p_i y_i} \qquad (20)$$

If the outputs are priced at marginal cost and if the production structure exhibits constant returns to scale. In this case, equation 19 becomes:

$$- \frac{\partial \ln g}{\partial T} = \sum_{i=1}^{m} r_i \frac{d \ln y_i}{dT} - \sum_{j=1}^{n} s_j \frac{d \ln x_i}{dT}, \qquad (21)$$

which is the same as the Divisia index of productivity discussed earlier (for a derivation of these results see Ref. 16).

For empirical investigations of the cost structure of firms, an explicit functional representation of equation 13 is required. A group of generalized or "flexible" functional forms has been proposed in the literature. These include the generalized Leontief, quadratic, and translogarithmic (translog) cost functions, as well as others (e.g., generalized Cobb-Douglas, generalized CES, etc.).

Among these various "flexible" functional forms, the translog cost function (Ref. 17) has been the most popular in empiri-

cal research in recent years. The translog cost function represents a second-order Taylor series approximation, in logarithms, to an underlying (unknown) cost (production) function. The general form of the translog cost function can be written as:

$$\ell n\ C = \gamma_o + \sum_i^m \gamma_i y_i + \sum_j^n \beta_j P_j$$

$$+ \frac{1}{2}\sum_i^m \sum_k^m \phi_{ij}\ \ell n\ y_i\ \ell n\ y_k$$

$$+ \frac{1}{2}\sum_j^n \sum_k^n \lambda_{jk}\ \ell n\ p_j\ \ell n\ p_k$$

$$+ \sum_i^m \sum_j^n \theta_{ij}\ \ell n\ y_i\ \ell n\ p_j \qquad (22)$$

such that

$$\sum_j \beta_j = 1\ ;\ \sum_k \lambda_{jk} = 0 \text{ for all } j\ ;$$

$$\sum_j \theta_{ij} = 0 \text{ for all } i\ ;\ \sum_j \lambda_{jk} = 0 \text{ for all } k.$$

These coefficient constraints are required by cost minimization.

The cost-share equations corresponding to equation 22 become:

$$\frac{\partial \ell n\ C}{\partial \ell n\ p_j} = \beta_j + \sum_k \lambda_{jk}\ \ell n\ p_k + \sum_i \theta_{ij}\ \ell n\ y_i \qquad (23)$$

The translog cost function of equation 22 and the factor cost-share equation 23, subject to the constraints on the coefficients, are estimated econometrically as a simultaneous equation system (e.g., through the use of the maximum likelihood method).

A.2.5 MEASUREMENT OF PRODUCTIVITY IN SERVICE INDUSTRIES: PROBLEMS AND APPROACHES

Over 70% of U.S. employment is currently in the service sector, which has accounted for much of the growth of jobs in the U.S. economy during the postwar period. Moreover, according to forecasts made available by the BLS, the service sector (including government) is expected to provide three out of four new jobs between 1980 and 1995. In view of these facts and of the overall productivity slowdown in the U.S. economy over the past decade, our current level of understanding of the dynamics of productivity performance in the sector must be noted, by all accounts, as quite crude and clearly inadequate.

The service sector encompasses a significantly large number of subsectors or industries producing a fairly heterogeneous set of outputs. These subsectors include the following (1982 employment levels, in thousands, and percent shares in total U.S. employment are noted in parentheses):

- Transportation, utilities and communications (5,543; 5.4%)
- Wholesale and retail trade (22,536; 22.0%)
- Finance, insurance and real estate (5,899; 5.8%)
- Services (22,617; 22.1%)
- Private households (1,635; 1.6%)
- Government (federal, state, local) (15,803; 15.4%)

Currently, the BLS compiles productivity data for 16 specific service industry categories and for federal government agencies, insurance, libraries, building and grounds maintenance,

and medical services. This work is currently being expanded to also cover commercial banking, insurance, and hospital industries.

In general, the problems associated with measuring productivity in the service industries are similar to those encountered for other industries. At an elementary level, a principal problem is one of serious data gaps. For example, information on hours worked by all persons--supervisor, nonsupervisory workers, self-employed and unpaid family workers--is lacking. Available data from the BLS Current Employment Survey are collected on an hours-paid basis rather than on an hours-worked basis. Further, the labor input data (person-hours) represent unweighted hours; that is, the hours of various types of employees are assumed to be equally productive. To the extent that there occur shifts in the composition of the workforce (e.g., age, sex, occupational mix), the resulting productivity measures would be affected, sometimes seriously.

A further, more difficult problem arises in measuring output. For example, when there are quality changes in the services provided, adjustments should be made in the output measure to account for the fact that the output is no longer a homogeneous unit. That is, the dollar measure of output may mask sometimes quite important shifts in the quality, as well as the mix, of services produced.

Measuring inputs is made more difficult at the conceptual level of specifying and estimating production (or generalized cost) functions at the firm or industry levels from which inferences can be made on productivity trends. Here, the presence of multiple outputs, joint costs, and scale economies (or "scope" economies in the case of multiple-product firms), as well as shifts in the underlying technology and changes in the quality of the services produced, create very difficult analytical issues.

A promising recent development in the specification and estimation of translog cost functions, which is particularly well suited to the analysis of productivity in service industries, is the "hedonic" cost function approach pioneered by Spady and Friedlaender (Ref. 18) in their path-breaking analysis of trucking firms. The simplest specification of the "hedonic" cost function is given by:

$$C = C\left[\Psi(y,t),\ w\right] \tag{24}$$

where y is ton-miles, w is a vector of factor prices (e.g., labor, capital, fuel, purchased transportation), t is a vector of summary measures of shipment characteristics and load factors (e.g., average shipment size, average length of haul, average load, percentage of tons shipped in LTL--less than truckload--lots, average insurance cost per ton-mile), and Ψ is a function of the form:

$$\Psi(y,t) = y\ \phi(t). \tag{25}$$

The important point to note in connection with this work and subsequent studies inspired by this work focusing on trucking firms (e.g., Refs. 19-22) is that qualitative variables affecting the structure of the firm's technology and costs are directly incorporated into the analysis. Thus, a "hedonic" cost function expresses costs as a function of 1) input prices, 2) some aggregated measure of the size of the multiple outputs (e.g., ton-miles), and 3) some "hedonic" variables pertaining to the firm's operating characteristics that describe, in a condensed form, the mixture of output quantities produced. Friedlaender, Spady and Wang Chiang (Ref. 21, p.81) note that the failure of earlier studies to model differences in operating characteristics (across firms) can lead to spurious inferences on such important areas of interest as economies-of-scale in the industry.

As mentioned earlier, the translog function has been used extensively in empirical work in recent years to study a diverse range of related subjects, including the cost structure and productivity of industries, economies-of-scale and scope in various industries, and demand for energy and interfuel substitution. Studies focusing on the structure of costs and productivity of various industries alone are quite extensive. In addition to the trucking industry already mentioned, these studies cover, for example, the following industry subsectors:

- The electric utility industry (e.g., Ref. 23);
- The automobile industry (e.g., Ref. 24);
- The railroad industry (e.g., Refs. 16, 25-27);
- Telecommunications (Refs. 28-30).

The econometric cost function approach to the measurement of productivity change, including these and other applications, typically assumes static profit maximization or static cost minimization, and also assumes that all inputs adjust fully to their long-run equilibrium levels within one time period (e.g., a year or a quarter). This represents a potentially serious shortcoming, inasmuch as in many industries such factor adjustments take time and do not follow such a neat timetable.

Further, straightforward application of the econometric cost function approach would fail to represent accurately the shifts in the cost of production function attributable to technical change in virtually all cases involving 1) nonconstant returns to scale, 2) nonmarginal cost pricing, and 3) effective rate-of-return regulation.

There have been a number of attempts recently to deal with these two sets of deficiencies associated with the econometric

cost function approach. For instance, a number of contributions to the theory of cost and production have proposed variable (restricted) profit or cost functional forms which are "flexible" but also recognize explicitly that in the short run certain inputs may be fixed. Another series of contributions have attempted to integrate dynamic costs of adjustment into the neo-classical theory of the firm. Much of this literature, however, has remained theoretical.

Meanwhile, other efforts to modify the econometric cost function approach to deal with the second set of problems (e.g., the failure of this approach in cases characterized by nonconstant returns-of-scale, nonmarginal cost pricing, presence of effective rate-of-return regulation) have met, at best, with mixed success.

A.2.6 CONCLUSION

The measurement of productivity growth, particularly in the service industries, is still at an embryonic stage, both conceptually and empirically. Considerable future promise, however, is offered by recent developments in econometric analyses of cost (production) functions, which allow for a more comprehensive and precise quantification of productivity performance, especially in the context of service industries characterized by multiple (heterogeneous) products, common and joint costs in the production process, economies of scale and scope, and important qualitative attributes associated with the outputs or with the underlying technological process.

The recent move away from the conventional index number TFP approach to the cost function approach is in general a welcome development, as demonstrated by the existing literature. This is because the cost function approach would, at least in principle, provide a conceptually acceptable way of developing a **causal** understanding of a complex set of influences conditioning produc-

tivity performance. However, a great deal more needs to be done in the future not only analytically, but also in terms of more reliable databases, before reliable measures of productivity performance can be developed. Further, theoretical and empirical efforts are needed to overcome the various strong underlying assumptions, implicit or explicit, that characterize the cost function approach (e.g., static cost minimization, full adjustment of all factors of production within each time period entering into the analysis, etc.).

In short, while the econometric cost function approach to TFP measurement is generally preferable to the conventional index number approach, much more yet needs to be done before the cost function approach would represent a reliable method for measuring the productivity performance of specific industry sectors or firms.

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B.1 "MACHINERY EXCEPT ELECTRICAL" (SIC 35)

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B.1 "MACHINERY EXCEPT ELECTRICAL" (SIC 35)

The machinery except electrical subsector, SIC 35, includes establishments engaged in manufacturing of all machinery and equipment other than electrical equipment (SIC 36) and transportation equipment (SIC 37). This is the largest manufacturing subsector, accounting for 12.8% of the manufacturing sector's contribution to GDP in 1980. The industry is characterized by:

- A high degree of fragmentation. Out of a total of approximately 48,200 establishments, 35,750 employed less than 20 persons (1977).

- A labor productivity of $23,117 per employee year or $12.04 per employee hour (1980, 1972 $), ranking this subsector eighth among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 1.5%/year from 1972 to 1980 ranking this subsector eighth. The labor productivity for the comparable Japanese subsector was $13,124 per employee year or $6.84 per employee hour (1980, 1972 $), ranking this subsector ninth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 5.2%/year from 1972 to 1980, ranking this subsector seventh.

- A slightly lower than average capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $23,117 in total assets per worker, ranking eighth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $1,824 per employee (1980, 1972 $), ranking ninth in the manufacturing sector.

Total capital productivity, measured as dollars of added value output per dollar of capital investment, was 0.72 (1981).

- A moderately aggressive R&D program. For the subsector as a whole, R&D expenditures amounted to $3.3 billion (1980, 1972 $), ranking this subsector third among the 10 manufacturing subsectors. R&D expenditures were equivalent to 5.9% of the value added by the subsector in 1980.

Table 1-1 lists the major products of each subdivision of the machinery except electrical subsector, ranked in descending order in terms of their share of the subsector's contribution to GDP in 1980. Table 1-2 summarizes the principal economic measures of these subdivisions.

As shown in Table 1-1, the greatest contributor to the value added of the machinery except electrical subsector is the office and computing machinery subdivision (SIC 357). The next two largest contributers are Construction Machinery and Equipment (SIC 353), and Metalworking Machinery (SIC 354). Office and computing machinery has been selected for detailed analysis because of the high level of technology it utilizes and the impact of its products on virtually every manufacturing industry. Metalworking Machinery (SIC 354) will also be investigated in light of new developments in cutting tools and materials handling systems in use throughout the manufacturing sector. Engines and Turbines (SIC 351) also warrant inspection because of the impact of new materials and computing capabilities on turbine development and design.

B.1.1 ENGINES AND TURBINES (SIC 351)

This subdivision consists of establishments primarily engaged in the manufacture of steam, water, and gas turbines,

TABLE 1-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE MACHINERY EXCEPT ELECTRICAL INDUSTRY (SIC 35) AND RELATIVE CONTRIBUTION TO TOTAL SUBSECTOR OUTPUT, 1980

SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
357	**OFFICE, COMPUTING, AND ACCOUNTING MACHINES**	18.3
	ELECTRONIC COMPUTING EQUIPMENT, CALCULATING AND ACCOUNTING MACHINES, SCALES AND BALANCES (EXCLUDING LABORATORY SCALES), TYPEWRITERS, TIME CLOCKS AND MISCELLANEOUS OFFICE EQUIPMENT.	
353	**CONSTRUCTION, MINING AND MATERIALS HANDLING MACHINERY AND EQUIPMENT**	17.3
	BULLDOZERS, CONCRETE MIXERS, CRANES, DREDGING MACHINERY, PAVERS, POWER SHOVELS, MINING EQUIPMENT, DERRICKS, BITS, ELEVATORS, ESCALATORS, CONVEYORS, HOISTS, TRUCKS, TRACTORS, TRAILERS, AND ACCESSORIES.	
354	**METALWORKING MACHINERY AND EQUIPMENT**	13.7
	METAL CUTTING AND FORMING MACHINE TOOLS, SPECIAL TOOLS, DIES, JIGS, AND FIXTURES, POWER DRIVEN HANDTOOLS, ROLLING MILLS, SHOP MEASURING DEVICES, AND OTHER METALWORKING EQUIPMENT, ROBOTICS, FLEXIBLE MANUFACTURING SYSTEMS, AND NUMERICALLY CONTROLLED MACHINE SHOP MACHINERY.	
356	**GENERAL INDUSTRIAL MACHINERY AND EQUIPMENT**	13.6
	PUMPS, COMPRESSORS, FANS AND BLOWERS, BEARINGS, GEARS AND MECHANICAL TRANSMISSIONS, PATTERNS, GENERATORS, STEAM SEPARATORS, LUBRICATING EQUIPMENT AND SYSTEMS, ATOMIC ENGINES, HYDRAULIC HOISTS AND EQUIPMENT, GENERAL INDUSTRIAL MACHINERY.	
359	**MISCELLANEOUS MACHINERY**	8.9
	CARBURETORS, PISTONS, PISTON RINGS, VALVES, CRANKSHAFTS, CAMSHAFTS, FILTERS, CYLINDERS, PUMP GOVERNORS, CAROUSELS, CATAPULTS, MACHINE SHOPS, AMUSEMENT MACHINES, AND CARNIVAL EQUIPMENT.	
358	**REFRIGERATION AND SERVICE INDUSTRY MACHINERY**	7.4
	VENDING MACHINES, COMMERCIAL LAUNDRY AND DRY CLEANING EQUIPMENT, AIR CONDITIONING AND WARM AIR HEATING EQUIPMENT, COMMERCIAL AND INDUSTRIAL REFRIGERATION EQUIPMENT, DISPENSING PUMPS, FLOOR SANDING, WAXING, AND WASHING MACHINES, COMMERCIAL OVENS, COMMERCIAL AND INDUSTRIAL VACUUMS, WATER FILTERS, AND COMMERCIAL WATER PURIFIERS.	
355	**SPECIAL INDUSTRIAL MACHINERY EXCEPT METALWORKING MACHINERY**	7.2
	FOOD PROCESSING, TEXTILE, WOODWORKING, PAPER PRODUCTS, PRINTING, SMELTING, REFINING, GLASS AND CEMENT MAKING, TOBACCO PRODUCTS MACHINERY KILNS, COTTON GINS, FOUNDRY, ELECTROPLATING, TANNING, RUBBER WORKING, PAINT MAKING, STONE WORKING, AND SHOEMAKING MACHINERY, NUCLEAR REACTOR CONTROL ROD AND DRIVE MECHANISMS.	
352	**FARM AND GARDEN MACHINERY**	7.0
	WHEELED TRACTORS, AGRICULTURAL MACHINERY, FARM EQUIPMENT, IRRIGATION EQUIPMENT, HARVESTING, GRADING, CLEANING, AND SORTING MACHINERY, LAWN MOWERS, ELECTRIC TRIMMERS, PLOWS, ROTOTILLERS, CARTS, AND SNOWBLOWERS.	
351	**ENGINES AND TURBINES**	6.6
	STEAM, HYDRAULIC, AND GAS TURBINES EXCEPT AIRCRAFT, COMPLETE TURBOGENERATOR SETS, STEAM GOVERNORS, WATER WHEELS, INTERNAL COMBUSTION AND DIESEL ENGINES FOR STATIONARY, MARINE, TRACTION, AND OTHER USES, TANK ENGINES, DIESEL GOVERNORS, OUTBOARD MOTORS.	
35	**ALL MACHINERY EXCEPT ELECTRICAL AND ELECTRONIC**	100.0

SOURCES: U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981
U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972

TABLE 1-2

SUBDIVISIONS AND CHARACTERIZATION OF THE MACHINERY EXCEPT ELECTRICAL INDUSTRY (SIC 35) DURING 1980, IN 1972 $

SUBDIVISION	PERCENTAGE CONTRIBUTION	NUMBER OF EMPLOYEES (1,000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL MACHINERY (35)	100	2,410.9	48,193	35,748	3,363	12,299	1,824	23,117
ENGINES & TURBINES (351)	7	125.5	316	147	110	21,399	1,987	29,329
FARM & GARDEN (352)	7	153.8	2,158	1,403	254	13,077	1,878	25,465
CONSTR., MINING, OIL FIELD (353)	17	364.0	3,230	1,711	580	15,184	2181	26,506
METALWORKING (354)	14	349.3	10,628	7,949	483	10,546	1,352	21,876
SPECIAL INDUSTRY (355)	7	203.4	4,087	2,601	400	9,554	1,142	19,827
GENERAL INDUSTRIAL (356)	14	344.9	4,947	3,141	635	12,303	1,469	21,905
OFFICE, COMPUTING, & ACCOUNTING (357)	18	381.4	1,313	704	345	12,061	2,939	26,676
REFRIGERATION & HEATING (358)	8	186.3	2,116	1,277	343	11,439	1,447	21,992
MISCELLANEOUS	8	302.3	19,398	16,815	213	9,346	1,530	16,490

[a] 1977

SOURCE: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981

with the exception of jet aircraft engines and automotive gas turbines. Internal combustion engines for use in heavy machinery, boats, and tanks are also manufactured by industries in this subdivision (internal combustion engines for motor vehicles are manufactured by industries in the transportation equipment subsector (SIC 37)). Establishments engaged exclusively in manufacturing internal combustion engine parts and turbogenerator parts and equipment are also included in this subdivision.

The engines and turbines subdivision accounted for 7.6% of shipments and 6.6% of the value added in the machinery except electrical subsector in 1980.

The business profile of the engines and turbines subdivision is pictured in Table 1-3. From 1972 to 1980, the constant dollar value of industry shipments grew at a compound annual rate of approximately 5.9%; shipments declined by 16.2% per year from 1980 to 1983. Industry employment followed a similar trend, growing at a rate of 2.7% per year from 1972 to 1979, and declining 11.6% annually from 1979 to 1983. Improvements are expected in 1984 for this industry, with employment rising 8% to 921,000, and with the constant dollar value of shipments rising 8% to $4.8 billion (1972 $).

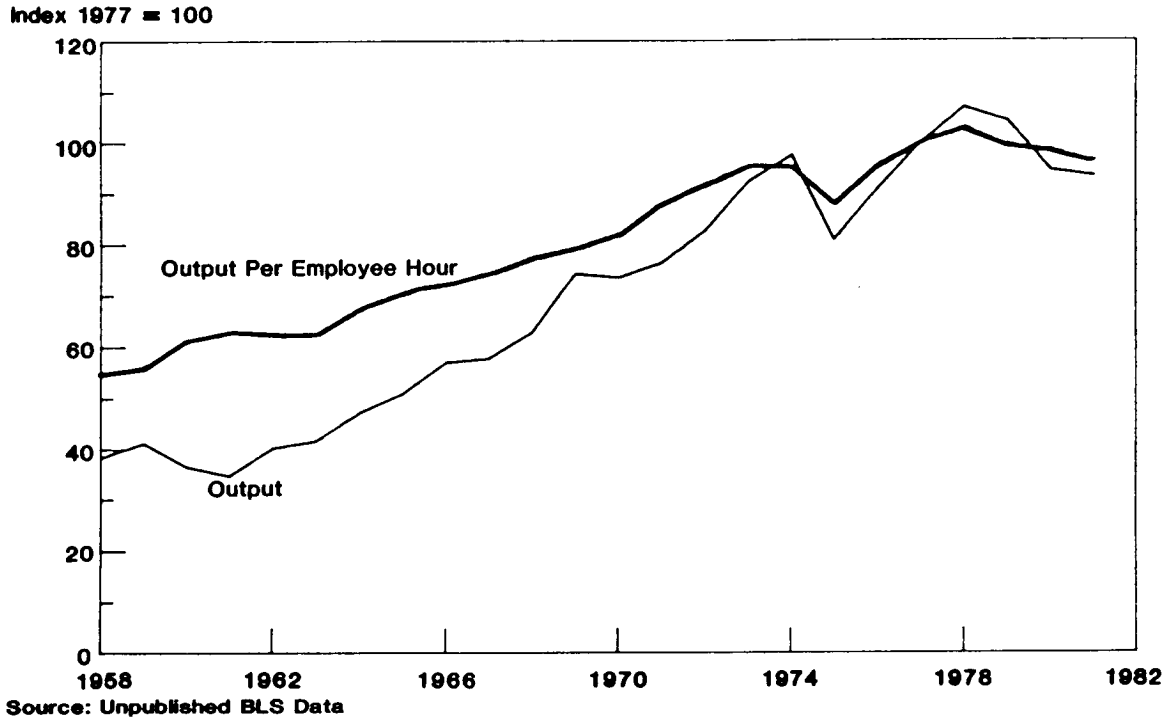
Table 1-4 represents the structural profile of the engines and turbines subdivision. The turbine manufacturing industry (SIC 3511) is not very fragmented; eight companies out of 86 establishments account for 98% of industry shipments. The engine industry (SIC 3519) is much more fragmented; over three hundred establishments manufacture a diversity of engines in this industry.

The production cost distribution for the subdivision is detailed in Table 1-4. Materials costs account for approximately one-half of production costs; capital and labor account for an additional 24% and 21.5% of production costs, respectively.

TABLE 1-3

BUSINESS PROFILE OF THE
ENGINES AND TURBINES INDUSTRY (SIC 351)

SHIPMENTS (BILLION $)	1972	1977	1979	1981	1982	EST. 1983	EST. 1984
CURRENT $	4.84	9.07	11.72	13.34	12.33	11.92	--
1972 $	4.84	5.84	6.28	5.60	4.75	4.45	4.80
TOTAL EMPLOYMENT (THOUSANDS)	116.1	129.7	139.5	125.6	105.1	85.3	92.1



Source: Unpublished BLS Data

PLANT CAPACITY UTILIZATION, %	1979	1981	1982
FOR ALL SIC 35	91	89	80

NEW CAPITAL EXPENDITURES	1980	1981
CURRENT $, BILLION	0.44	0.72

SOURCES: U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981
U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK

TABLE 1-4

STRUCTURAL PROFILE OF THE
ENGINES AND TURBINES INDUSTRY (SIC 351)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	147
INTERMEDIATE (20-1000)	135
LARGE (>1000)	34
TOTAL (255 COMPANIES)	316

LEADING FIRMS (1983)

NAME	DOMESTIC SALES ($ MILLION)
COMBUSTION ENGINEERING	1,113
BRIGGS AND STRATON	571
CUMMINS ENGINE	514
McGRAW EDISON	397

	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	13.5%	8.0%	50.5%	4.2%	23.8%

R&D FUNDING $ MILLIONS	1980	1981
	150	175

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
1984 VALUE-LINE INVESTMENT SURVEY

Approximately 74% of all workers involved in manufacturing internal combustion engines are production workers; approximately 61% of all workers involved in turbine manufacturing are production workers. A high number of turbine industry employees are engineers involved with the design and testing of turbines and components. About 85% of engine and turbine R&D funding is contributed by industries within the subdivision; the balance is supplied by the federal government.

The dominant constraints (see Table 1-5) on the engines and turbines industry are essentially market-related. Engines must be safe, reliable, and as nonpolluting as possible. Internal combustion engines are subject to the same market growth trends as industries that incorporate these engines in their machinery. The demand for internal combustion engines should grow about 6% per year through the next decade. Orders for turbomachinery generally originate from either power plants or shipbuilders; thus, this industry has an even more specialized clientele than nonautomotive internal combustion engine producers. New orders for turbines are scarce since most utilities are concentrating expenditures on meeting pollution standards and reducing operating costs, instead of providing capital expenditures on new equipment.

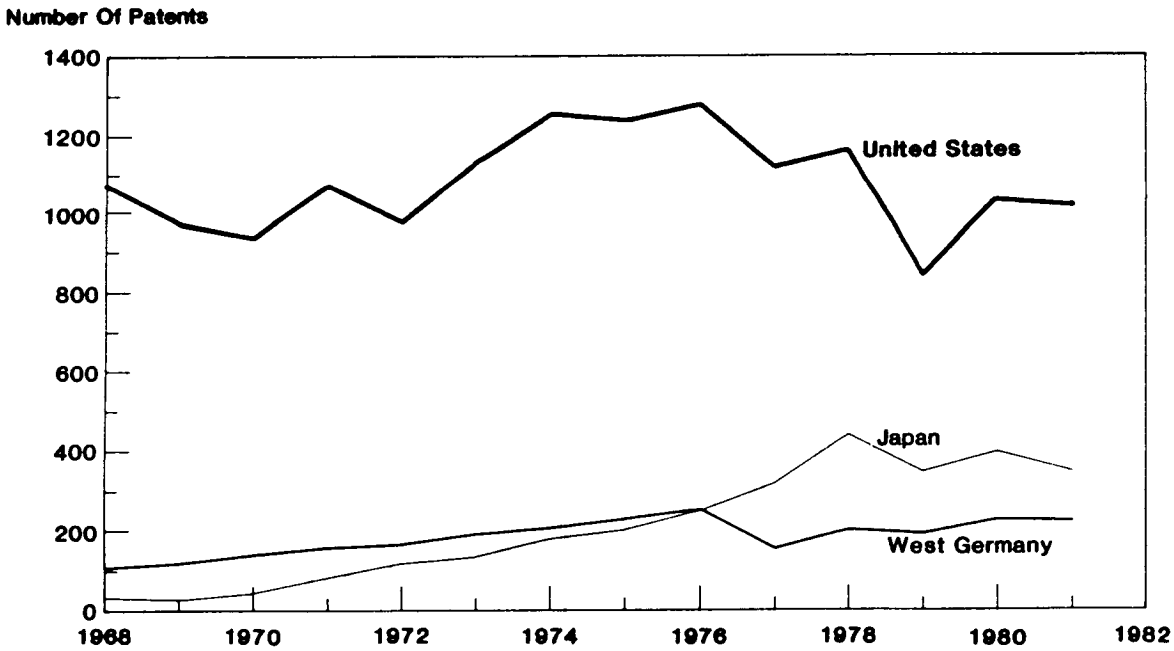
Competitive Issues Affecting the Engines and Turbines Industry

In recent years, the demand for internal combustion engines (excluding automotive and aircraft engines) and turbines has decreased. While U.S. exports grew at a compound annual rate of about 20% from 1972 to 1981, exports fell by about 16% per year from 1981 to 1983. In addition, imports rose at a compound annual rate of 20% from 1972 to 1979; since 1979, imports have been declining by about 5% yearly. The total positive U.S. balance of trade grew at a compound annual rate of 16.6% from 1972 to 1983.

TABLE 1-5

DOMINANT CONSTRAINTS AFFECTING THE ENGINES AND TURBINES INDUSTRY (SIC 351)

CONSTRAINT	PRINCIPLE IMPACT
FISCAL/MONETARY POLICY	STRONG DOLLAR LIMITS EXPORTS WHILE HIGH INTEREST RATES LIMIT DOMESTIC SALES.
LIMITED MARKET/CUSTOMERS	KEY CUSTOMERS ARE UTILITIES THAT CURRENTLY HAVE HIGH GENERATING RESERVES.
REGULATORY ENVIRONMENT	ENGINE MANUFACTURERS MUST COMPLY WITH FEDERAL CLEAN AIR REQUIREMENTS. UTILITIES ARE UNABLE TO PURCHASE NEW EQUIPMENT ECONOMICALLY AS A RESULT OF SLOW FEDERAL RESPONSE TO REQUESTED RATE INCREASES.
LIMITED CAPITAL FOR UTILITIES	UTILITIES' EQUIPMENT EXPENDITURES GO TO UPGRADING AND EXTENDING THE LIFETIME OF EXSISTING FACILITIES INSTEAD OF NEW EQUIPMENT PURCHASES.



Source: National Science Foundation

Figure 1-1. Number of Patents Issued for Engines and Turbines for the U.S. and its Chief Competitors

An indication of the future competitiveness and novelty of the engines and turbines subdivision is the patent output by various countries within this industry. Such data are displayed in Figure 1-1 for the U.S. and its leading competitors. Thus, Japan and F.R. Germany, show positive growth rates in the number of patents issued (20% and 5.6%, respectively), despite the industry slowdown after 1979.

In general, U.S. exports are dropping while imports are rising for a combination of reasons. The U.S. dollar has remained very strong in comparison to foreign currencies. Some U.S. markets are declining (for example, the power industry), while others seem saturated.

Productivity in the Engines and Turbines Industry

The figure in Table 1-3, drawn from unpublished BLS data, shows that labor productivity (output per employee hour) rose steadily through 1973. Following 1973, productivity dropped for two years, then started to climb again. Since 1978 productivity has remained constant. Labor productivity is currently the highest among all the machinery except electrical manufacturing industry subsectors (SIC 35), with a constant 1972 dollar value of $29,329 per employee year in 1980.

The engine and turbines subdivision is also the highest contributor to the subsector in terms of gross value of fixed assets, amounting to $21,399 per employee in constant 1972 dollars. Capital productivity, on the other hand, amounted to $0.72 of added value output per dollar of capital investment in 1981, which was average among manufacturing industries. Capital productivity is not as high as labor productivity because small batches, requiring extensive labor, are usually produced.

Material costs account for the largest proportion (50%) of production costs for engine and turbine manufacturers. These

costs consist of metals (30%) and purchased parts, bearings, rivets, screws, valves, carburetors, etc. (70%).

Role of Technology in the Long-Term Strategic Outlook

The engines and turbines industry is a saturated industry that depends upon the performance of the power industry and industries that utilize small internal combustion engines. Shipments of internal combustion engines (about 70% of all subdivision shipments) should rise 6% per year through 1990. Shipments of turbines and turbine generator sets have fallen significantly since 1972; only a major upward shift in the nation's power demand would result in increased purchasing of turbines and related equipment.

New metalworking technologies are important to engine and turbine manufacturers. Robotics and manufacturing cells could lead to large gains in manufacturing productivity. Computer-aided engineering designs, coupled with integrated computer-aided manufacturing, would be especially beneficial to turbine manufacturers since complex blade and shroud shapes are difficult and time consuming for a machinist to produce. Explosive forming offers time and energy saving alternatives to component manufacturing. Spin forging saves material and production time for round parts or solids of revolution, especially those with complex thickness tapers. New tools for metals and composites are allowing the manufacturers and designers to utilize new materials.

New materials technologies include carbon-matrix composites, metal laminates, powder metallurgy, and advanced ceramics. These new materials reduce the weight of new designs and increase fuel efficiencies and product lifespans. The fluid chromate treatment increases turbine blade lifespans by creating a bonded iron-chromium surface that retards the outward migration of iron and the inward diffusion of oxygen. These new materials technologies

are expected to increase operating temperatures, which will yield improved thermal efficiencies for both turbines and internal combustion engines.

The turbine industry has also been among the first industries to utilize the new generation of supercomputers to perform computational fluid dynamics. Computational fluid dynamics enable the designer to model fluid flow by numerically solving the Euler and the Reynolds-averaged Navier-Stokes computations for two-dimensional, nonlinear inviscid flow and for three-dimensional flow. Designers are thus able to visualize flow patterns and experiment with blade shapes in order to optimize turbine efficiency.

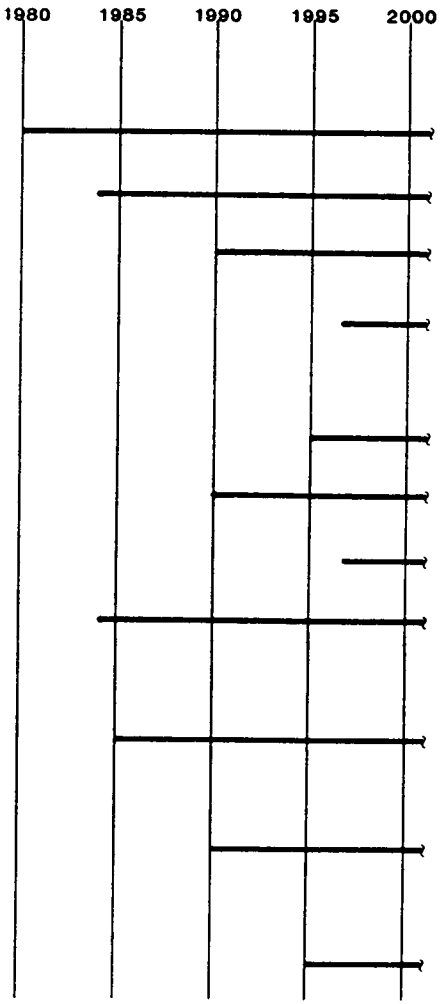
Another important tool is nondestructive evaluation (NDE), which allows engine designers and utilities to extend the lifespan of their turbines. In 1978, nearly half of all U.S. fossil fuel plants experienced some type of turbine blade failure, with resulting costs from downtime and repair amounting to around $265 million. NDE offers a variety of techniques for examining turbine blades for flaws prior to failure during scheduled shutdowns. Engine wear can also be evaluated without destroying the integrity of parts. While NDE is not a new technology per se (visual inspection has always been important in determining maintenance requirements), industry standards are currently being developed for the wide range of NDE methods, from ultrasonics and radiography to surface examination methods. Moreover, the American Society of Mechanical Engineers has formed its newest subdivision (NDE Engineering Subdivision) for the purpose of fostering knowledge of NDE methods throughout industry.

Table 1-6 summarizes key new technologies affecting the engines and turbines subdivision.

TABLE 1-6

EMERGING ENGINE & TURBINE TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT
COMPUTATIONAL FLUID DYNAMICS	NUMERICAL SOLUTIONS OF FLUID DYNAMICS PROBLEMS INVOLVING COMPLEX GEOMETRIES.	TURBINE DESIGN AND FLOW VISUALIZATION.
• STAGE 1	LINEARIZED INVISCID COMPUTATIONS FOR ATTACHED FLOWS.	
• STAGE 2	NONLINEAR INVISCID (EULER) COMPUTATIONS.	
• STAGE 3	REYNOLDS-AVERAGED NAVIER -STOKES COMPUTATIONS.	
• STAGE 4	FULL NAVIER-STOKES CAPABILITIES FOR COMPLETE TURBULENCE COMPUTATIONS.	
MATERIALS		
• ADVANCED CERAMICS	HIGH TEMPERATURE, HIGH-STRENGTH ENGINE COMPONENTS.	INCREASE THERMAL EFFICIENCY.
• CARBON-MATRIX COMPOSITES	HIGH TEMPERATURE, HIGH STRENGTH ENGINE COMPONENTS.	INCREASE OPERATING TEMPERATURE AND LIFESPAN.
• ADVANCED METAL TECHNOLOGY	METAL LAMINATES, POWDERED MATALLURGY, ETC.	INCREASE PRODUCT LIFESPAN.
• FLUID CHROMATE TREATMENT	RETARD THE IRON OXIDATION PROCESS FOR TURBINE BLADES.	INCREASE PRODUCT LIFESPAN.
MANUFACTURING SYSTEMS		
• SPIN FORGING	TWO SPINNING ROLLERS SHAPE SPINNING WORK PIECE (FOR SOLIDS OF REVOLUTION).	REDUCE COMPONENT WEIGHT REDUCE ADDITIONAL MACHINING.
• FLEXIBLE MANUFACTURING	AUTOMATED WORK CELL CONSISTING OF COMPUTERIZED NUMERICALLY CONTROLLED MACHINING OPERATIONS WITH ROBOTICS TRANSFER MECHANISMS ADAPTABLE TO SMALL BATCH PROCESSES.	INCREASE PRODUCTIVITY
• INTEGRATED MANUFACTURING	FMS WITH DIRECT LINK TO CAD COMPUTERS.	INCREASE PRODUCTIVITY, ENABLE DESIGNER TO UPGRADE PART DESIGN WHILE ON-LINE.



SOURCES: AVIATION WEEK AND SPACE TECHNOLOGY, SEPT. 3, 1984
MECHANICAL ENGINEERING, FEB 1984.

Conclusion

The growth of the engines and turbines subdivision is constrained by the growth rate of electricity generating utilities and shipbuilding industries, as well as the durable goods manufacturers that utilize miscellaneous internal combustion engines in their products. Current U.S. generating capacity exceeds requirements, and, although most utilities are growing about 9% yearly, there is very limited purchasing to expand generating capacity. Consumer confidence is up recently, thus there is sustained growth in the purchasing of durable goods that incorporate internal combustion engines, such as powerboats, small generators, lawnmowers, etc. It is doubtful that the demand for miscellaneous internal combustion engines will rise to previous (1979-1980) levels.

Further growth of the engines and turbines subdivision is limited. Barring another oil crisis, the internal combustion engines manufacturing subdivision should experience a sustained growth rate in shipments of 6%. The projected date for a significant upswing in orders for turbines and generators is 1989, and several years must pass for this upswing in orders to result in an increase in shipments. Since most of the manufacturers of power generating equipment are large diversified companies, the capacity for increasing shipments will exist until demand rises again.

B.1.2 METALWORKING MACHINERY AND EQUIPMENT (SIC 354)

The National Machine Tool Builders Association (NMTBA) defines a machine tool as "a powered device, not hand-held, which cuts, forms or shapes metal." It performs operations of turning, milling, drilling, boring, grinding, threading, pressing, bending, and die-casting. Approximately 80% of all machine tools remove metal, the rest shape metal by deformation. Related activities of the industry include the production of robots, of

woodworking machines, of specialized dies and tools. Machine tools are primarily produced by the metalworking industry for sale to end-user manufacturing industries. However, several large manufacturing companies have in-house capabilities for designing, developing and producing specialized machine tools for their own use.

The U.S. Cabinet Council on Commerce and Trade, in its report "An Assessment of U.S. Competitiveness in High Technology Industries," states "a healthy machine tool industry is considered an important element of the U.S. Industrial base." A strong and sophisticated machine tool industry is also desirable for strategic reasons, i.e., to enable the U.S. to meet the increased military production required in times of national emergency.

Moreover, technological progress tends to spread from the machine tool industry into the rest of the manufacturing sector. Figure 1-2 shows the relationship between the machine tool industry and other industries.

The business profile, structural profile and principal socioeconomic and institutional constraints of this subdivision are summarized in Tables 1-7 through 1-9, respectively.

Table 1-7 shows that the constant dollar value of shipments peaked in 1980 at $10 billion, but has since returned to the 1972 value of around $7 billion. Total industry employment also peaked in 1980 and has also returned to the 1972 value of approximately 270,000 employees. Industry output fluctuations tend to follow those of major consumers such as transportation equipment, fabricated metals, and other machinery. The figure in Table 1-7, drawn from unpublished BLS data, shows that productivity (overall output) has risen steadily, with one downturn in the mid 1970s. Labor productivity (output per employee hour), however, has been declining from its 1977 peak level.

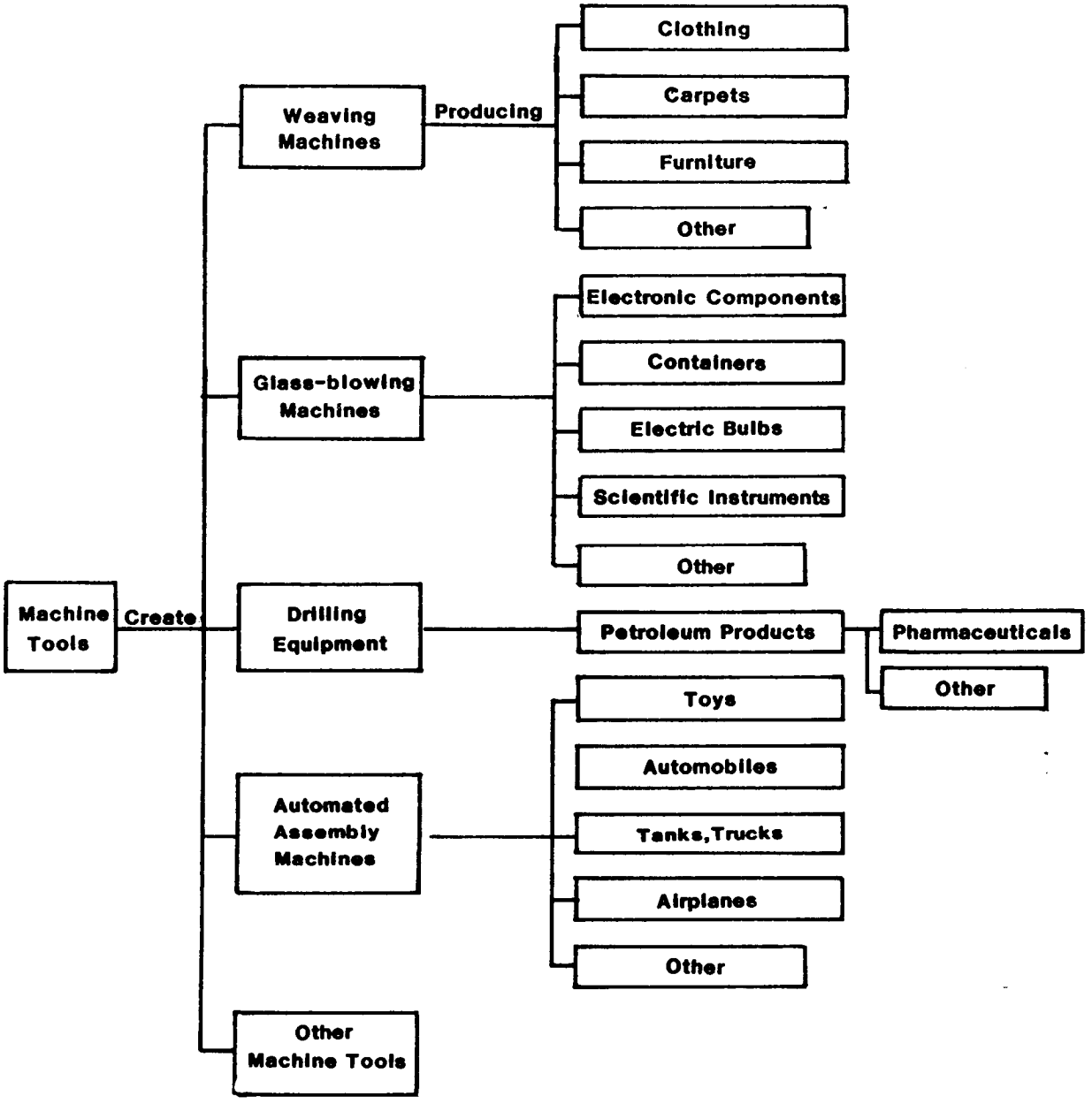
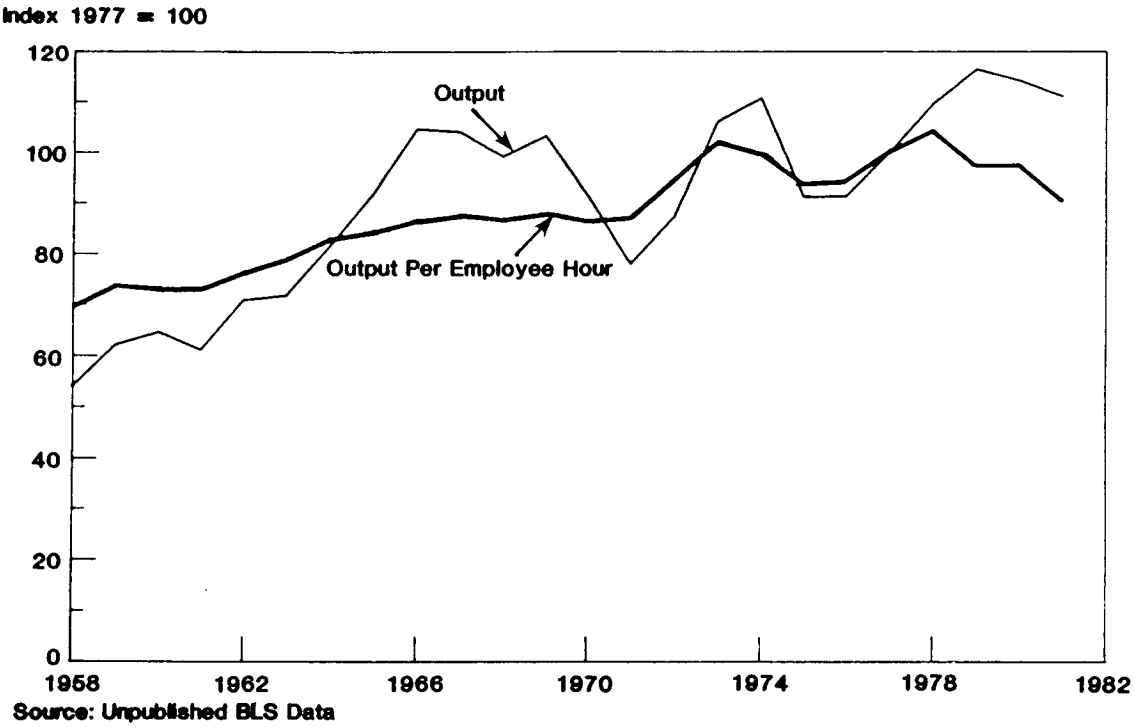


Figure 1-2. Impact of Machine Tool Industry on Manufacturing Sector

TABLE 1-7

BUSINESS PROFILE OF THE
METALWORKING AND MACHINE TOOL INDUSTRY (SIC 354)

SHIPMENTS (BILLION $)	1972	1977	1980	1981	EST. 1982	EST. 1983	EST. 1984
CURRENT $	7.3	13.3	21.1	22.3	16.1	14.5	—
1972 $	7.3	8.3	10.2	8.9	7.9	7.0	7.3
TOTAL EMPLOYMENT (THOUSANDS)	268.2	297.8	349.3	341.8	335.0	270.0	—



Source: Unpublished BLS Data

PLANT CAPACITY UTILIZATION, %	1979	1981	1982
FOR ALL SIC 35	91	89	80

NEW CAPITAL EXPENDITURES	1980	1981
CURRENT $, BILLION	0.843	0.919

PRE-TAX PROFIT, 1980, % OF SALES 8

RETURN ON INVESTMENT, 1980, % 18

VALUE OF PLANT, 1976, BILLION CURRENT $ 1.4

AVERAGE ORDER-TO-DELIVERY CYCLE 9 TO 12 MONTHS

BACKLOG, MONTHS	1979	1981
	16	9

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK

TABLE 1-8

STRUCTURAL PROFILE OF THE
METALWORKING AND MACHINE TOOLS INDUSTRY (SIC 354)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	7949
INTERMEDIATE (20-1000)	2657
LARGE (>1000)	22
TOTAL	10628
(10265 COMPANIES)	

LEADING FIRMS (1983)

NAME	DOMESTIC SALES (MILLION $)
CINCINNATI MILACRON	326
CONDEC	251
EX-CELL-O CORP.	162
ACME CLEVELAND CORP.	152
CROSS & TRECKER CORP.	111
GLEASON CORP.	76
BROWN & SHARP MFG.	55
MONARCH MACHINE TOOL CO.	52
VERMONT AMERICAN	48

PRODUCTION COST DISTRIBUTION, 1977	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
	22.3%	11.7%	35.0%	1.0%	30.0%

INTERNAL R&D EXPENDITURES, % OF SALES: 2%

INNOVATION LEAD TIME, YEARS: 3 TO 5

PREVALENT MODE OF PROCESSING
75% BATCH — LESS THAN 50 ITEMS

AGE OF PLANT, YEARS

	10	10-20	20
1963	35%	45%	20%
1978	31%	35%	34%

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984
NATIONAL ACADEMY OF ENGINEERING: THE COMPETITIVE STATUS OF THE U.S. MACHINE TOOL INDUSTRY.

TABLE 1-9

CONSTRAINT PROFILE OF THE METALWORKING AND MACHINE TOOL INDUSTRY (SIC 354)

GOVERNMENT INTERACTION	ANTI-TRUST CONSTRAINS INTER-INDUSTRY COOPERATION, LIMITS BENEFITS OF R&D.
GOVERNMENT REGULATION	OSHA, PRODUCT LIABILITY--ADD TO OVERHEAD COSTS.
OWNERSHIP STRUCTURE	INDUSTRY FRAGMENTATION LIMITS R&D EFFORT OF SMALLER INDUSTRIES.
WORKER AGE	AVERAGE SKILLED OPERATOR AGE: 58
AVAILABILITY OF YOUNGER WORKERS	LIMITED.
TRAINING PERIOD FOR SKILLED OPERATOR	8000 HRS, 4 TO 5 YEARS.
AVERAGE QUALITY OF MANAGEMENT	NOT TECHNICALLY ADEQUATE. MANY ARE FROM RANKS OF CRAFTSMEN, NOT UNIVERSITY TRAINING. LIMITED ENTREPRENEURSHIP.
QUALITY OF ENGINEERING	300 PHDs REQUIRED PER ANNUM.
AVAILABILITY OF ENGINEERING	SCARCE SUPPLY. SALARY AND SOCIAL ATTITUDE TOWARDS ENGINEERS SEVERELY LIMITING.
FISCAL-MONETARY POLICY	SENSITIVE TO TAX CREDITS.
AVAILABILITY OF INVESTMENT CAPITAL	INADEQUATE TO REGAIN MARKET FOREFRONT. HIGH RISKS, LOW ROI, UNCERTAIN CASH FLOW, DETER INVESTORS.
MARKET DEMAND PATTERN	HIGHLY CYCLICAL, MAGNIFIED BY FINAL USER INDUSTRIES' BUSINESS CYCLE.

The machine tool industry is highly fragmented, with about 75% of its establishments employing less than twenty persons. The five largest companies in the industry accounted for only 7% of the value of 1983 industry shipments.

The production cost for metalworking machinery and machine tools is distributed nearly evenly among materials, labor, and capital. Materials costs account for 35% of production costs with metals comprising approximately 75% of these materials. Capital accounts for 30% of production costs, a value which is surprisingly low considering the in-house technology available to this industry to upgrade plants. Manufacturing labor accounts for a large portion (22.3%) of production costs in this industry, while other labor accounts for approximately half of this value. This manufacturing subdivision is therefore more labor intensive in production than in engineering, a characteristic corroborated by its low level of internal R&D expenditures.

The machine tool industry is undergoing significant structural changes. Caution prevails among manufacturing industries with regard to new machine tool purchases, with most of their orders geared toward replacement equipment. New technologies are changing marketing strategies. Large industries are being targeted for the most advanced automation (such as flexible manufacturing systems, machining cells, robotics, etc.), while for smaller establishments, new products are being developed that utilize the most technology for the least cost (such as a personal computer-controlled and monitored machine tool, etc.). The nature of international competition has changed as the major foreign supplier to the U.S. has shifted from F.R. Germany and its conventional machinery to Japan and its numerically controlled machinery.

The future performance of the metalworking machinery subdivision is difficult to predict because of the problematical situation faced by its customers, who would be forced to automate

their factories to be competitive. The purchase of big ticket, automated manufacturing machinery would be vulnerable to a drop-off in shipment volume, leaving a plant running below capacity and burdened with large overhead payments.

Competitive Issues Affecting the Machine Tools Industry

The competitive posture of the U.S. machine tools industry has eroded significantly, both in the foreign and the domestic market place. Constraints on U.S. machine tool exports are the strong U.S. dollar, high U.S. interest rates, and lagging foreign markets resulting from worldwide recession. Traditional leading markets for U.S. exports have collapsed. From 1982 to 1983, exports to Mexico have dropped by 77%; exports to Canada by 47%; exports to the U.K. by 58%; exports to Japan by 15% (1983 $). Meanwhile, government-subsidized foreign machine tool manufacturers are penetrating the U.S. domestic market with products priced below U.S. prices.

From 1972 to 1981, U.S. exports of machine tools rose at a compound annual rate of 16.5% to a peak value of about $1.03 billion. Since 1981, exports have declined at a rate of 38% per year. Foreign imports have behaved in a similar fashion; from 1972 to 1981, imports grew at an annual rate of 33% to $1.5 billion, while from 1981 to 1983 they declined 18% per year. Thus, the overall balance of trade declined by around 14% per year from 1972 to 1983, from $146 million surplus in 1972 to $610 million deficit in 1983. Correlatively, imports accounted for a 10.2% share of consumption in 1972; by 1983, this share reached 39%.

In 1982 the chief foreign supplier to the U.S. domestic market shifted from F.R. Germany to Japan. Imports from Japan equaled $529 million in 1982, followed by F.R. Germany with $205 million, the U.K. with $108 million, and Taiwan with $91 million. Whereas the U.S. formerly imported standard precision machine tools from the European Economic Community (EEC), it now imports

sophisticated, numerically controlled machinery and machining centers from Japan and low-cost cutting tools from Taiwan. In addition, much of this large inventory of imported machinery is being offered at discount prices.

In response to these trends, domestic manufacturers are pressuring the federal government to deny investment tax credits to U.S. companies that purchase Japanese machinery, by authority of Section 103 of the Revenue Act of 1971; and to provide import relief to U.S. manufacturers under Section 232 of the Trade Expansion Act of 1962. These acts have been justified by the claims that the Japanese have formed an illegal cartel in the machine tool industry and that the protection of domestic markets from excessive imports is in the interest of national security.

The recent erosion of U.S. leadership in the machine tool industry is depicted in Table 1-10.

Productivity in the Machine Tools Industry

The figure in Table 1-7, drawn from unpublished BLS data, shows that labor productivity in the machine tools industry (output per employee hour) rose approximately 29% from 1958 to 1981, a low performance considering the in-house technology available to boost productivity.

The general nature of machine tool manufacturing is labor intensive. Training a skilled machine tool operator typically requires 8,000 hours or about four years. Shop managers are usually experienced operators with little or no college level management education.

Future gains in labor productivity will probably be made by automating certain factories at the expense of some employees' jobs. Since labor costs account for 34% of production costs, there are large profits to be gained by automating factories and

TABLE 1-10

COMPETITIVE POSTURE OF METALWORKING (MACHINE TOOL) INDUSTRY (SIC 354)

SHARE OF WORLD MARKET, %

PRODUCTION	1976	1980
U.S.	16	18
EEC	35	33
JAPAN	7	14
ALL OTHERS	42	35
CONSUMPTION		
U.S.	15	20
EEC	22	23
JAPAN	6	10
ALL OTHERS	57	47

EXPORTS, % PRODUCTION

U.S.	23	16
EEC	48	41
JAPAN	34	40

IMPORTS, % CONSUMPTION

U.S.	14	24
EEC	17	20
JAPAN	15	7

NEW TECHNOLOGIES, NUMBERS INSTALLED, 1980

	NC	ROBOTS	FMS
U.S.	70,000	4,100	19
EEC	70,000	3,000	15
JAPAN	50,000	14,250	33

reducing the workforce. In addition, establishments showing marginal profitability may be forced out of business.

Materials account for 35% of production costs, while capital costs account for 30% in the machine tools industry. The majority of materials needed are metals; production runs are usually batches of fifty parts or less. While this industry is ideally suited for flexible manufacturing systems, decreasing product demand and a lack of captial for new expenditures make such an upgrade risky and too expensive. Less drastic upgrades could be instituted, however, by replacing aging machinery with more modern equipment, such as new cutting tools with faster cutting speeds, adaptive controls, high energy rate forming techniques, and robotic material handlers. Small companies may find it in their interests to join together in the formation of consortiums to permit investment in these productivity improvement devices.

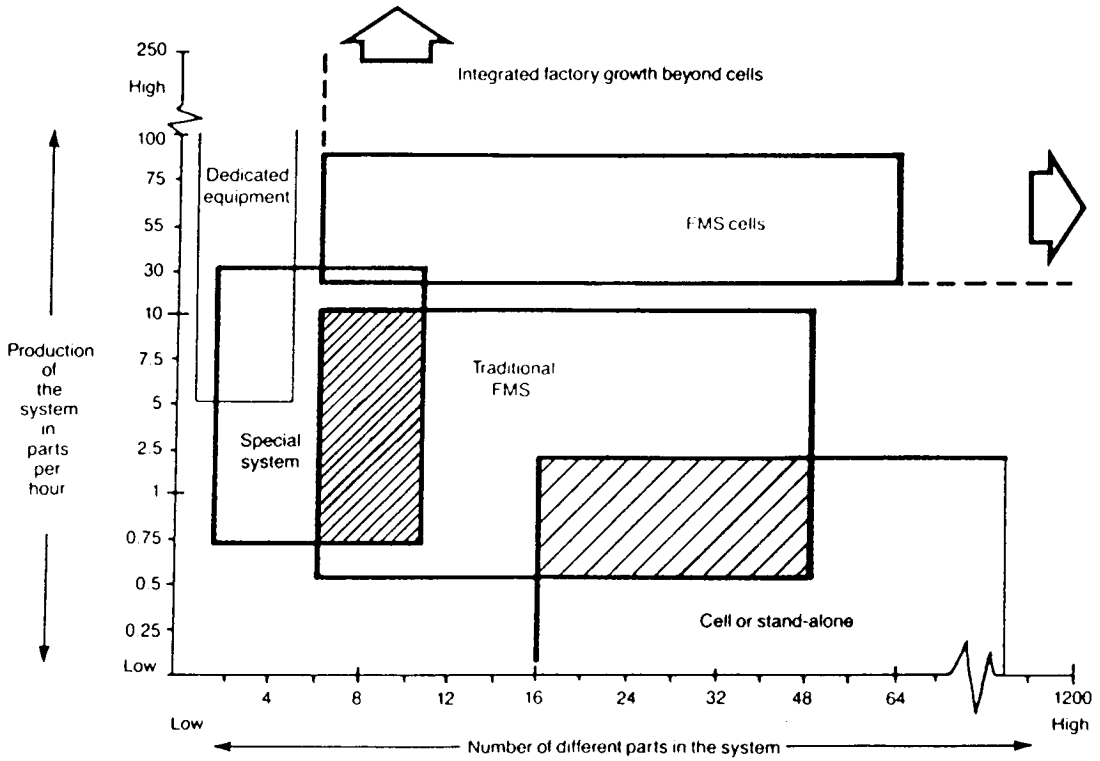
It is worth noting that the current obsolescence of metalworking plants may well represent a benefit: since plants have to be modernized anyway, a rational program of modernization may lead to a substantial gain in productivity. At the same time, the quality of new machinery can provide closer tolerances. However, this is often a small factor in determining product value, because in many instances tolerances are already adequate. Quality of design for low cost manufacturability is far more critical to the achievement of product quality. In general, timely product delivery and reliability of spare parts and the service supply chain are hardly impacted by the modernization of plant machinery. Far more important is the management and scheduling of the product design and manufacturing phases.

The problem of capital reinvestment in the plants of the metalworking industry goes beyond the issue of replacement of equipment into that of manufacturing philosophy. The worldwide trend is toward the incorporation of flexibility criteria within the manufacturing plant, i.e., the capability to handle product

variety or product changes with a minimum of downtime or capital reinvestment. Since batch manufacturing of less than 50 pieces accounts for approximately 75% of the metalworking machinery manufacturing performed in the U.S. (see Table 1-7), it is crucial that the industry implement changes in manufacturing philosophy with the flexibility to integrate all manufacturing-related operations. Principal developing technologies in this respect are manufacturing cells and flexible manufacturing systems. A manufacturing cell is a group of machine tools which is serviced by a materials handling device, coordinated and paced by a computer or program controller. Parts can be rapidly transferred from one machine tool to the other, with a minimum of waiting time and inventory. A flexible manufacturing system is a group of manufacturing cells serviced by several materials handling devices, with a computer responsible for coordinating, pacing and scheduling.

A useful tool for choosing the most productive automated manufacturing system is the volume-variety chart in Figure 1-3. For low variety (up to 5 different parts) and high volume (over 5 or 10 parts per hour) production, dedicated equipment such as a transfer line is the most productive factory automation feature. For high variety (over 16 different parts) and low volume production (less than 3 parts per hour), work cells or stand alone machining centers consisting of several numerically controlled machine tools are preferable. This latter system offers the most flexibility in terms of variety of parts produced (300 or more various types of parts per year), but should not be used when the total yearly production quantity per part exceeds 50.

Mid-volume/mid-variety production refers to a large segment of current production needs, and includes yearly production rates of 15 to 15,000 for any one part number, and part numbers processed by a system ranging from 2 to 3000 per year. For the low variety (2 to 8 part numbers), high volume (1500 to 15,000 workpieces per year) end of the mid-volume/mid-variety production



Volume-variety chart.

Source: Mechanical Engineering, October 1984

Figure 1-3. Volume-Variety Chart

segment, special systems featuring computerized numerically controlled (CNC) machine tools are recommended. The most flexible production systems, manufacturing cells, are recommended for the high variety (4 to 3000 part numbers per year), low volume (15 to 500 workpieces of one part number per year) production needs. Flexible manufacturing is designed for mid-variety (4 to 3000 various part numbers per year), mid-volume (4 to 2000 workpieces of one part number per year) production. These flexible manufacturing systems (FMS) are groups of machine tools interconnected by robotics and automatically guided vehicles for workpiece transfer. Typically, an FMS will process a family of parts. Incorporation of the proper automated manufacturing systems is improving the level of equipment utilization; with automated material and workpiece handling, equipment utilization rates rise to over 80%.

Historically, the U.S. metalworking industry has reacted to innovation instead of taking a direct part in development of technology. This may be a possible cause of the relatively poor current posture of this industry.

Recently, under the pressure and threat of foreign competition, particularly Japanese, some members of the industry, principally numerically controlled (NC) machine tools, computer-aided design/computer-aided manufacturing (CAD/CAM), have fostered the implementation of new technology within their own manufacturing operations. The incorporation of these new technologies into the industry's final products is accelerating, as shown in Table 1-11.

However, although NC machine tools, for example, have been available since the late 1950s, their actual penetration into industrial plants has been slight (see Table 1-12) and they have been mostly acquired from outside suppliers. In addition, the number of robots actually introduced into metalworking plants has been relatively low (see Table 1-10); it is, however, important to note that the definition of "robots" varies among countries.

TABLE 1-11

TOTAL U.S. SHIPMENTS OF MACHINE TOOLS AND NUMERICALLY CONTROLLED MACHINE TOOLS

YEAR	TOTAL THOUSAND $	NC MACHINES THOUSAND $	NC AS % OF TOTAL
1977	1,791,293	496,741	27.7
1978	2,207,585	649,215	29.4
1981	4,046,940	1,370,823	33.9
1982	2,922,245	1,093,159	37.4

TABLE 1-12

NUMERICALLY CONTROLLED MACHINE TOOLS IN THE U.S.

YEAR	INSTALLED THOUSANDS OF UNITS	% OF TOTAL POPULATION OF MACHINE TOOLS
1958	0	0
1963	5	0.3
1968	14.5	0.7
1973	30	1.2
1977	55	1.8
1983	105	3.6

The level of modernization within the U.S. metalworking industry is shown by the relative age of plants (see Table 1-8). The tendancy over the last decade has been to defer the replacement of aging capital equipment, resulting in the use of machine tools that are generally older than those used in the past. The replacement of this equipment has been made more difficult by the excess plant capacity prevalent over the past few years, coupled with low return-on-investment (ROI) and profits. However, the recent increase in the operating capacity of the metalworking industry--from 68% in 1982 to a projected 76% in 1984--does begin to justify an increased capital investment in equipment modernization.

The modernization of aging equipment is the short-term remedy to improve the productivity and competitiveness of the metalworking industry. This remedy would suffice for approximately five years. Beyond 1988-1990 new approaches are mandated by the fact that the industry's competitiveness will be increasingly based on

- product cost,
- product quality,
- timeliness of product delivery, and
- efficiency of the spare parts supply chain and the associated services.

The "breakthrough" potential is represented by the achievement of integrated, computerized, end-to-end functions. This involves 1) design functions supported by computer-aided design (CAD); 2) planning via computerized project and material requirements planning systems; 3) manufacturing using computerized NC machines (CAM), preferably joined into FMSs; 4) inspection through computerized coordinate measuring machines and automated

test equipment; 5) materials and parts storage in automated warehouses; 6) material movement by automated material handling systems; 7) electronic linkages between functions which must communicate; 8) a database architecture designed to permit common access to data shared among functions; 9) eventually, computer-assisted end-to-end engineering based upon the mere statement of requirements--i.e., computer-assisted engineering (CAE).

Current technology has addressed the computerization of individual functions and activities, e.g., CAD, NC and CNC machines, robotics. The implementation of these individual "islands of automation" does not require redesign of the current organizational relationships or changing the philosophy of the manufacturing organization.

The medium-term step, estimated to begin reaching fruition circa 1990-1995, is the generation of the technology and methods for developing the integrated structure. Many companies are attacking the problem because of the anticipated major improvement in challenging competition. The anticipated advantages are illustrated in Table 1-13.

TABLE 1-13

COST AND TIME SAVINGS FROM NEW TECHNOLOGIES IN METALWORKING (MACHINE TOOL) INDUSTRY

TECHNOLOGY	ERA OF FRUITION	END-TO-END NORMALIZED PROCESS TIME	TOTAL PRODUCTION COSTS, NORMALIZED
CONVENTIONAL MANUAL	CURRENT	100	100
CAD/CAM	1987-90	85	75
CAE	1990-95	65	55-60

Role of Technology in the Long-Term Strategic Outlook

Declining shipments and employment, together with a market showing a high degree of constraints, result in a "sunset" designation for the metalworking machinery and equipment subdivision (SIC 354). Considering the strategic importance of this industry to most other U.S. manufacturing industries, it is important to assess technologies that will provide short and long-term fixes. The rest of this section is devoted to assessing and summarizing these technologies.

Table 1-14 summarizes the technologies currently entering and reportedly planned to enter the machine tool industry in the near and medium-term. Most of these are heavily dependent on digital electronic information processing. Taken together, they portend a system approach to product design, ultimately encompassing 1) multi-unit operations processing centers, interconnected by, 2) a common digital information network and, 3) directed and controlled by a CAE system. CAE refers to component and/or product design generated from requirements only.

Advancement of cutting technology will remain a continuous challenge into the foreseeable future.

Applications of and improvements in the technologies indicated in Table 1-14 can be expected to dominate this industry through the mid 1990s. As time elapses, gains in both capability and productivity are expected to become increasingly dependent on ever more limited human intervention in discrete process steps and improvement in the characteristics of materials.

In this context, consider the growing role assumed by robots. Robots are not machine tools, but are devices used to greatly increase the utilization of machine tools by replacing human operators. Suitably programmed, one robot can service several machine tools, loading and unloading work pieces, and

TABLE 1-14

PRINCIPAL SHORT AND MEDIUM-TERM TECHNOLOGIES
ENTERING THE METALWORKING (MACHINE TOOL) INDUSTRY

TECHNOLOGY	DESCRITPION	APPROXIMATE ERA OF SIGNIFICANT DIFFUSION 1980 1985 1990 1995
MACHINE TOOL CONTROLS		
• NUMERCIAL CONTROL (NC)	MIT-ORIGINATED IN THE 1950s. ARE ESSENTIALLY PREPROGRAMMED SERVODRIVERS.	
• COMPUTERIZED NC (CNC)	FLEXIBLE NC. CAN DRIVE MULTIPLE MACHINING & MATERIALS HANDLING OPERATIONS. 50% OF U.S. MANUFACTURERS PLAN TO BUY CNCs BY 1988.	
• ADAPTIVE MACHINE TOOL CONTROLS	CLOSED LOOP FEEDBACK CONTROL SYSTEMS THAT SENSE THE DIMENSION OF A PART BEING MACHINED AND AUTOMATICALLY CORRECT FEED, SETTING, SPEED. ADVANCED AMTC PROVIDE EARLY INDICATION OF TOOL WEAR, ENABLING TOOL CHANGE BEFORE DAMAGING WORKPIECE.	
MACHINE TOOL CONFIGURATIONS		
• MANUFACTURING CELLS (MC)	GROUP OF MACHINE TOOLS SERVICED BY A MATERIALS HANDLING DEVICE, COMPUTER COORDINATED.	
• FLEXIBLE MANUFACTURING SYSTEM (FMS)	GROUP OF MCS SERVICED BY MATERIALS HANDLING SYSTEM. COMPUTER COORDINATED, PACED AND SCHEDULED.	
• ROBOTS	SUBSTITUTE HUMANS IN PERFORMING TASKS e.g., LOADING AND UNLOADING WORK PIECES, CHANGING TOOLS. IN U.S. USED PRIMARILY FOR PAINTING, WELDING, MATERIALS HANDLING. GROWING USE IS FOR ASSEMBLY.	
COMPUTER-ASSISTED PRODUCTION		
• COMPUTER-AIDED DESIGN (CAD)	ASSISTS DESIGNERS IN BETTERING PRODUCT, AUTOMATE DRAWINGS, PROGRAMMING MACHINE TOOLS.	
• COMPUTER-AIDED MANUFACTURING (CAM)	OPTIMIZES SELECTION OF PROCESSES, EQUIPMENT, TOOLING, OPERATING CONDITIONS. LESS WIDESPREAD IN U.S. THAN CAD.	
• COMPUTER-AIDED ENGINEERING (CAE)	AUTOMATES ENGINEERING FUNCTIONS FROM REQUIREMENTS ONLY.	
METAL REMOVAL		
• FASTER CUTTING TOOLS	THROUGH IMPROVED TOOL MATERIALS. BY 1990 UP TO 12,000 SURFACE FPM FOR ALUMINUM, 3,000 SURFACE FPM IRON & STEEL. ALSO CERAMICS, TUNGSTEN CARBIDE/COBALT, NEW TOOL COATINGS.	
• HOT MACHINING	FOR VERY HARD MATERIALS. PLASMA TORCH PREHEATS METAL JUST AHEAD OF CUTTING TOOL.	
• ELECTRICAL DISCHARGE MACHINES (EDM)	REMOVES METAL VIA CONTROLLED ELECTRIC POWERED THERMAL REACTION.	
• ELECTRO-CHEMICAL MACHINING (ECM)	ELECTRIC ENERGY CREATES CHEMICAL REACTIONS WHICH DISSOLVE METAL FROM WORKPIECE INTO ELECTROYLIC SOLUTION.	
• LASER MACHINING	FOR CUTTING, WELDING, DRILLING, HEAT TREATING.	
ADVANCED MATERIALS	IMPROVED STEEL AND CAST IRON CASTINGS, ALUMINUM & COPPER FOR SOME PARTS PLASTICS REINFORCED WITH BORON, GRAPHITE, SILICON CARBIDE USE OF PRECISION CASTINGS AND FORGINGS.	

-----= 15% Diffusion

changing cutting tools as required. The number of robots in use in U.S. manufacturing companies is likely to at least triple during the next ten years. Nearly half the assembly of U.S. cars is expected to be accomplished by robots by 1990. For example, General Motors plans to spend over $1 billion on the introduction of 14,000 robots into its factories by 1990.

To what extent will the near and medium-term technologies indicated in Table 1-14 serve to correct the eroding posture of the metalworking industry?

The answer is obviously a function of the timeliness, completeness and thoroughness with which these technologies will be introduced. The tempo and extent of their introduction, estimated on the basis of current plans (see Table 1-14), substantially parallels similar efforts and plans in other runner-up nations. A reasonable estimate is that the introduction of these known technologies will suffice to maintain and perhaps somewhat improve the U.S. posture in the machine tool subsector, but should not be expected to lead to major "leap frog" steps.

The fundamental reason is that these technologies are aimed at correcting problems and improving situations which are easy to perceive, because they are natural evolutions of the state-of-the-art. Foreign runner-up nations are able to address the same short-term problems. In other words, these technologies address tactical rather than long-term strategic challenges.

Innovative, long-term technologies, which could allow the U.S. to regain a major leading role in the metalworking industry, are those which seek to correct basic, underlying problems. The nature and magnitude of these problems are derivable from the basic strengths and weaknesses of the industry associated with the factors conditioning productivity, as shown in Figure 1-4.

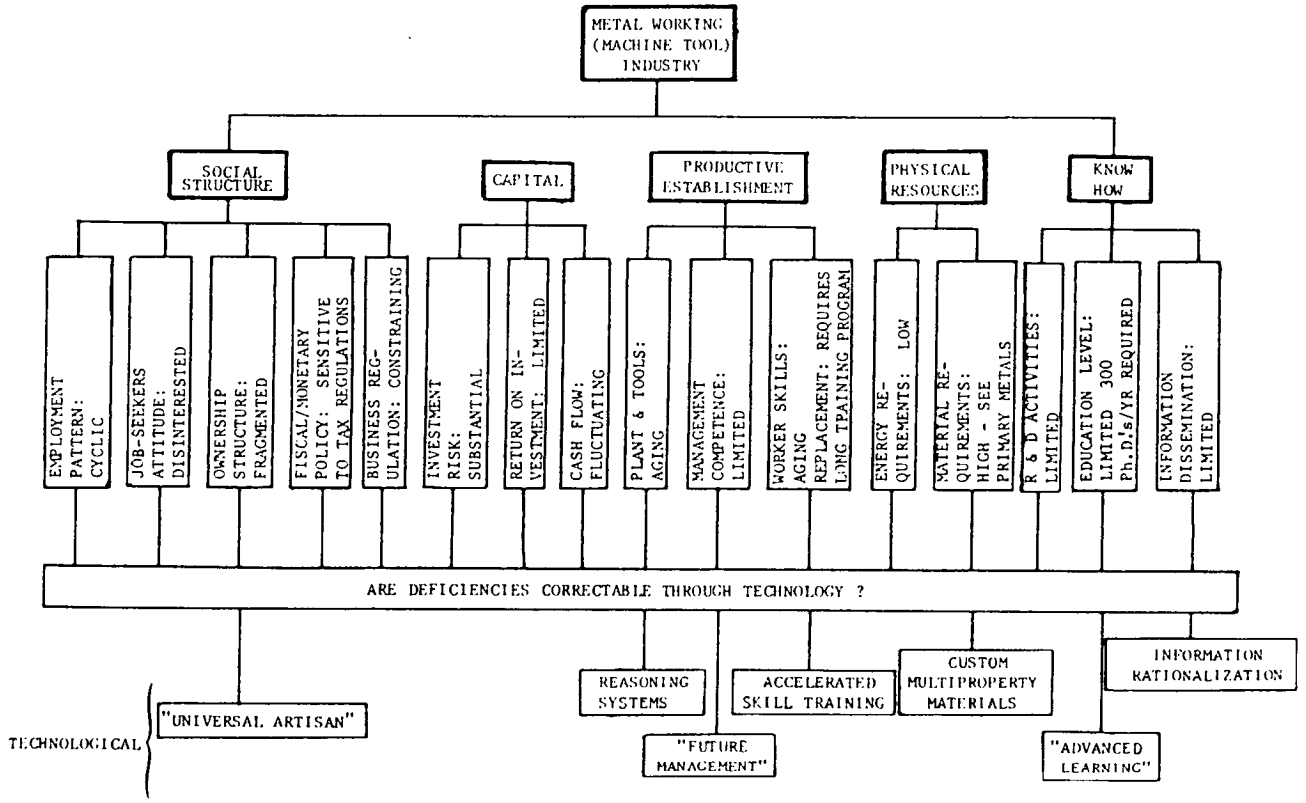


Figure 1-4. Long Range Strategic Technological Requirements

It can be seen from the Figure that a number of the strategic problems in the metalworking industry are not correctible directly and immediately through the application of technology; for example, the problem posed by the cyclic employment pattern. The emphasis here is on "directly and immediately." Clearly, improvements of productivity will induce a beneficial effect throughout the subsector. The direct achievement of productivity gains occurs through the introduction of innovative technologies. The technological requirements for a productivity revolution in the metalworking industry, as shown in Figure 1-4, are summarized in Table 1-15 and briefly discussed in the following subsections.

"Univeral Artisan"

The fragmentation of the metalworking (machine tool) industry poses distinct problems that derogate from achieving increased productivity:

- Achievement of economies-of-scale through conventional methods (e.g., use of large facilities, sophisticated "conventional" automation, merger of overhead functions) is virtually impossible.

- Significant investments in R&D through current methods (e.g., in-house developments by each industry) are severly limited by the scarce resources available to the individual small establishments.

- The situation is further aggravated by the "batch" nature of product demand.

In the normal course of events, this situation--which is common to other industries within the manufacturing sector--might resolve itself through the workings of socioeconomic forces--e.g., the exit of the smaller establishments, or their gradual

TABLE 1-15

LONG-TERM STRATEGIC TECHNOLOGICAL REQUIREMENTS
FOR METALWORKING (MACHINE TOOL) INDUSTRY

REQUIREMENT	DESCRIPTION
"UNIVERSAL ARTISAN"	THE ULTIMATE CAPABILITY SMALL MACHINE SHOP, WHICH CAN ADAPT RAPIDLY AND EFFICIENTLY TO DRASTICALLY DIFFERING ITEMS OF SMALL LOT PRODUCTION MANUFACTURING TOOL MANAGEMENT, AND MACHINE TENDING.
NEW SKILL TRAINING	RAPID EFFICIENT TRAINING IN MOTOR AND PERCEPTIVE SKILLS, COGNITIVE AND DECISION-MAKING SKILLS.
"FUTURE MANAGEMENT"	DEVELOPMENT AND APPLICATION OF INNOVATIVE METHODS AND TECHNIQUES OF MANAGEMENT.
CUSTOM MULTIPROPERTY MATERIALS	GENERATION OF MATERIALS WITH PREDICTABLE PHYSICAL PROPERTIES AND PREDETERMINED DIMENSIONS TO MEET HIGHLY DIVERSE END PRODUCT REQUIREMENTS.
REASONING SYSTEMS	DATA HANDLING AND MANIPULATIVE SYSTEMS CAPABLE OF PERFORMING HIGHER INTELLECTIVE FUNCTIONS—COMMONLY KNOWN AS "ARTIFICAL INTELLIGENCE."
ACCELERATED LEARNING	RAPID ACQUISITION OF BASIC EDUCATION.
INFORMATION RATIONALIZATION	"INTELLIGENT" INFORMATION SYSTEM CAPABLE OF EXTRACTING COGENT TOPICAL INFORMATION FROM DATA BASES FROM MINIMAL INPUT COMMANDS.

absorption by the larger concerns, or extreme ratio--the transition of the entire industry to foreign shores, or through the introduction of innovative institutional mechanisms--the formation of "consortia" or "cooperatives" sharing diverse functions of the production process or common R&D pools, or utilizing common overhead functions such as accounting. However, these socioeconomic and/or institutional solutions are not addressed in this effort as they lie outside the direct purview of technology.

From a technological standpoint, such a highly fragmented industry has many points of similarity with the "artisan shop" typical of the Renaissance and still widely established in European countries.

The artisan shop specialized (and still does) in batch or custom products. Its workers were (and still are) by and large highly flexible, endowed with multiple skills or with unique skills which command specialized quality markets (e.g., tool and die makers). It operates on a limited capital investment. Its internal R&D is virtually nonexistent; only the fruits of external R&D--e.g., more advanced equipment--are acquired by the industry, from the outside.

In the contemporary environment, a similar, small industry structure might be designated "universal artisan" in which specialized market "niches" are carved out and combined with highly innovative and cost-effective technologies.

The ultimate concept of the "universal artisan" would likely be embodied by a few individuals within a small enterprise, whose function would be to make decisions based on alternatives presented by a comprehensive information system. The decisions would be effected only at the general level (what to produce, by what time, in what amount for what profit margin). Most actions and decisions below this level would be accomplished by adaptive, intelligent automatons. The full fruition of such an enterprise

is likely to be achieved somewhat beyond the horizons of this study. Many key elements of the "universal artisan" are, however, evolving now and can be expected to be in place by the year 2000 (see Table 1-13).

The key technological thrust leading to the "universal artisan" would be the intelligent, business-oriented combination of certain key technologies:

- Multi-functional robots with limited learning capability;
- Comprehensive, highly rationalized information systems;
- Utilization, and adaption to small scales, of the most appropriate technologies of skilltraining, advanced management, information rationalization (see the following sections).

New Skill Training

Training of a skilled machine tool operator currently requires approximately 8,000 hours, i.e., four years. The evolving technology of the metalworking industry will increasingly emphasize the combining of mechanical skills with electronic and computer-oriented training to cope with the evolving automation of the metalworking systems. Further, the rapid evolution of the technology is expected to require a concurrent evolutionary pace of human adaption, i.e., frequent upgrading of already learned skills.

Skill, as it is here used, connotes the ability to perform specific tasks or groups of tasks, generally with a certain degree of repetitiveness, by the exercise of motor and perceptive functions. As such, the meaning of "skill" is distinct from that of basic education, whose aim is to train the higher reasoning faculties.

Forecasts by the Bureau of Labor Statistics indicate that by the year 2000 approximately 3% of the U.S. workforce is expected to be continuously engaged in retraining activities. This situation will require the development of major technologies and methods of providing rapid skill training.

Considerable attention has been devoted over the last four decades to improving skill training: by government agencies--e.g., DOD's AFSC-5 program, HEW training for the underprivileged; by private industry--e.g., IBM's programming schools; and by public and private institutions offering vocational training in a large number of specialties--TV, auto, and home appliance repair, plumbing and air conditioning care.

However, no major "breakthrough" in skill training has occurred. Possibly the most advanced current development is represented by "total immersion" techniques, offered primarily for the accelerated learning of foreign languages.

The long-range requirement is for the development of technologies aimed at:

- Scientific understanding of the mechanisms underlying skill learning;
- Generation of techniques for assessing a priori the aptitude of subjects towards acquiring skill training;
- Development of psychological, physiological and/or physical/neural techniques for alleviating impediments and enhancing propensities acting to restrain or to foster skill training.

"Future Management"

The machine tool industry is predominantly (75%) composed of small firms of less than twenty employees (see Tables 1-7 and 1-

8). Small batch lot production in plant facilities, 60% of which are more than 10 years old, characterize the industry. Management is largely represented by skilled craftsmen who rise to manage the operations they have performed. These individuals develop their management skill on the job, having little or no exposure to system management techniques nor cognizance of innovative technologies.

The evolution of the industry is characterized by increasingly integrated systems operations and the necessary supporting information systems. For the small machine tool industry manager to become more effective, an awareness of the available external system management tools and the skill to use those management tools internally are necessary. Based on the systems management approaches of the aerospace, electronics and other industries in such programs as the NASA Apollo program, an innovative management system technology, tailored to the machine tool industry, is needed to support the growth of management capability. Such an innovative management system requires:

- the imparting of a measure of basic education and skill training;
- systems and procedures developed for use in similar, but not necessarily identical operations;
- systems and procedures tailored to the skill levels of the management;
- user-friendly integrated information systems which can be directed and controlled effectively by internal management for both production and financial control.

The long-term technology thrust would foster the advancement of technologies associated with:

- measurement of management effectiveness in planning, direction and control;

- interrelationship of financial and production control;

- improvement of management skills on the job without disruption to production.

These and other technologies for improved machine tool industry management must meet the challenge of:

- flexibility--diverse, small firms;

- limited skill training--largely self-trained management;

- purposeful access to innovative product knowledge and to management system techniques.

Custom Multiproperty Materials

Traditionally, the machine tool industry has made products by grinding, milling, boring, piercing and similar operations all aimed at shaping rough bodies of material to specified dimensions and attributes (hardness, ductility, tensile strength, etc.). The closer such rough bodies approach the finished dimensions of the final product, the less the "finishing" costs. Recently, considerable attention has been devoted to this aspect of the industry. Since approximately 35% of the distribution of costs within the industry are materials (see Table 1-7), technologies leading to improving both the bulk projections and microproperties of materials input, or to substituting less costly and more abundant materials, can make a significant contribution to improved productivity. The technologies of materials with advanced attributes (reduced corrosion, reduced wear, super strength, etc.) transcend the machine tool industry, leading to strategic requirements to:

- investigate methods to produce tailored products with precisely controlled micro and bulk properties (for machine tools and the products from machine tools);

- accommodate substitution of low-cost and readily available materials, with equivalent or improved attributes, to contemporary materials; and,

- generate new materials with superior performance.

Reasoning Systems

Various social structures have been employed throughout history to increase labor productivity through "reasoning systems." In the past, such reasoning systems have been based on groupings of people. For example, division of slave labor into skill groups to provide cheap specialized labor has been practiced well into modern times. With the demand for productivity improvement, the guild system of the middle ages evolved, creating an artisan class at a still higher reasoning system level. Capital investment then began to supplement the artisan and preserve the knowledge essential to his reasoning system.

In the modern world the knowledge base has grown so diverse and complex that fragmentation may actually retard productivity growth. Modern industry has responded by creating many highly diverse specialized systems with heavy capital investment geared to augment, with information and communication equipment, reasoning systems which are largely human-based.

The availability today of embryonic, adaptive, computer-based systems portends the prospect of a revolution in reasoning systems. The essential attributes of these systems are:

- adaptability (universality);

- independent function (generalize instruction only); and
- ability to "learn" (cope with novelty).

Reasoning systems epitomize the current and near-future evolution of broad-based flexible manufacturing. This analogue to the artisan society is a timeless slave without human exploitation.

These reasoning systems will likely evolve from the body of technologies which include advanced programming, expert systems and the general area conventionally designated as artificial intelligence. It is too early to determine whether such systems will be inanimate or biologically based or both. The availability of such reasoning systems, as discussed in the foregoing, could well change not only the nature of the machine tool industry but our approach to all manufacturing in the 2000-2010 era.

Accelerated Learning

Up to five or six decades ago, the U.S. educational system, tailored on the European elitist system, was second to no other country in quality. It underwent a major transition, however, in the early 20th century because of the rapid evolution of mass education. The results have been spectacular from the viewpoint of interpersonal equality. Intermediate education has become accessible to all; higher learning to a large segment of the population. This U.S. example in mass education is currently being followed by all developed nations.

However, this dramatic expansion of the educational base has unavoidably challenged the system; achievement of quality had to be tempered against the goal of wide-spread diffusion. As a result, the quality of the end-product, the trained scientist and engineer, has suffered.

Moreover, the heretofore unparalleled rate of technological evolution can be expected to impose ever-more stringent constraints on the need for frequent upgrading of theoretical and applied basic learning. Increased demands upon machine tool planners and operators have intensified this need for rapid and accurate learning and periodic upgrading of learning. For example, as the machine tool industry has advanced in sophistication of unit operations, the complexity of interface with its equipment has increased. Simple measurement of set-up and operational checking have been replaced by present programming, programmed equipment adjustment and multiple operations control, through both analogue and digitally controlled subsystems.

The following salient elements of a long-range, directed learning policy, are similar to those presented above for skill training (the content would of course differ):

- scientific understanding of the mechanisms underlying basic learning;

- generation of techniques for assessing a priori the aptitude of subjects towards acquiring basic learning, and in what areas;

- development of psychological, physiological and/or physical/neural techniques for alleviating impediments and enhancing propensities acting to restrain or to foster basic learning.

Information Rationalization

The contemporary expansion of information, frequently referred to as the "information explosion," is well known.

Contemporary technology attempts to facilitate the conveyance of this information to, and its assimilation by the human

user, through the establishment of databases, i.e., repositories of data structured for user accessibility.

In the U.S. there currently exist approximately 850 such databases, encompassing environmental, industrial, natural resources, socioeconomic, medical and numerous other fields. These databases are variously accessible through the mails, through personal queries, and/or via teleprocessing.

However, users must have rather extensive knowledge of how a database is structured and organized in order to retrieve information from existing databases. The aim of a long-term technology thrust would be to develop procedures whereby a user can obtain the information of interest in a "transparent" fashion, i.e., from very limited, even "inexpert" inquiry directives. A pertinent analogy is that of replicating DNA-like mechanisms. Once the basic DNA "seed" is introduced in the appropriate medium, it automatically induces the growth of a structured organism. Likewise, an advanced information retrieval system of the future could act to aggregate cogent information into a basic "instruction kernel" provided by the user.

In the case of the machine tool industry, the need to gather and assimilate design, development and testing information in a form relevant to the manufacturer of single or multiple components has increased. Improved information rationalization would facilitate the quick accumulation of diverse, accurate information tailored to specific component manufacturers.

Conclusion

The chief constraint affecting the growth of the metalworking machinery manufacturing subdivision is the cyclical nature of demand in the machine tools market. These oscillations in demand cause or contribute to other problems in manpower, capital accumulation, and technological innovation. It is especially taxing

on a small machine tool manufacturer to train a novice operator for 4 years in a cyclical market, which discourages job seekers. A result of this depressed employment outlook is that the average age of skilled operator is 58 years. Most managers lack university training, and there is a shortage of manufacturing engineers specializing in machine tools. Problems in capital accumulation arise from the lack of effective management, which does not consider the high cost of inventories or effective utilization of floor space. It is difficult for small companies to build up enough cash for R&D expenditures in a cyclical market, thus this industry responds to technological innovations instead of initiating them.

Specific needs of the metalworking industry are listed below.

- Machine tool firms must evolve countercyclical strategies by adopting a varied product mix, developing market skills for new markets, and maintaining flexible manufacturing capabilities.

- There must be more information sharing and cooperative ventures between manufacturers, vendors, and customers.

- The industry should collaborate with universities, technical schools, and government to advance R&D, particularly in new materials.

- The industry should develop closer ties with foundries to address the problem of deteriorating casting quality.

- The industry should participate more fully in adopting international machine tool standards.

B.1.3 OFFICE, COMPUTING, AND ACCOUNTING EQUIPMENT (SIC 357)

The office, computing, and accounting equipment subdivision, SIC 357, consists of establishments primarily engaged in manufacturing computers, typewriters, word processors, adding machines, and cash registers. Those electronic components and accessories, such as integrated circuits and semiconductor memories, that are incorporated into most of this industry subdivision's products are not included in this subdivision, but are classified under Electrical and Electronic Machinery, Equipment, and Supplies (SIC 36). In addition, software packages and computer systems engineering, germane to this industry in computer design and marketing, are also categorized under another industry heading, Computer and Data Processing Services (SIC 737) of Business Services (SIC 73).

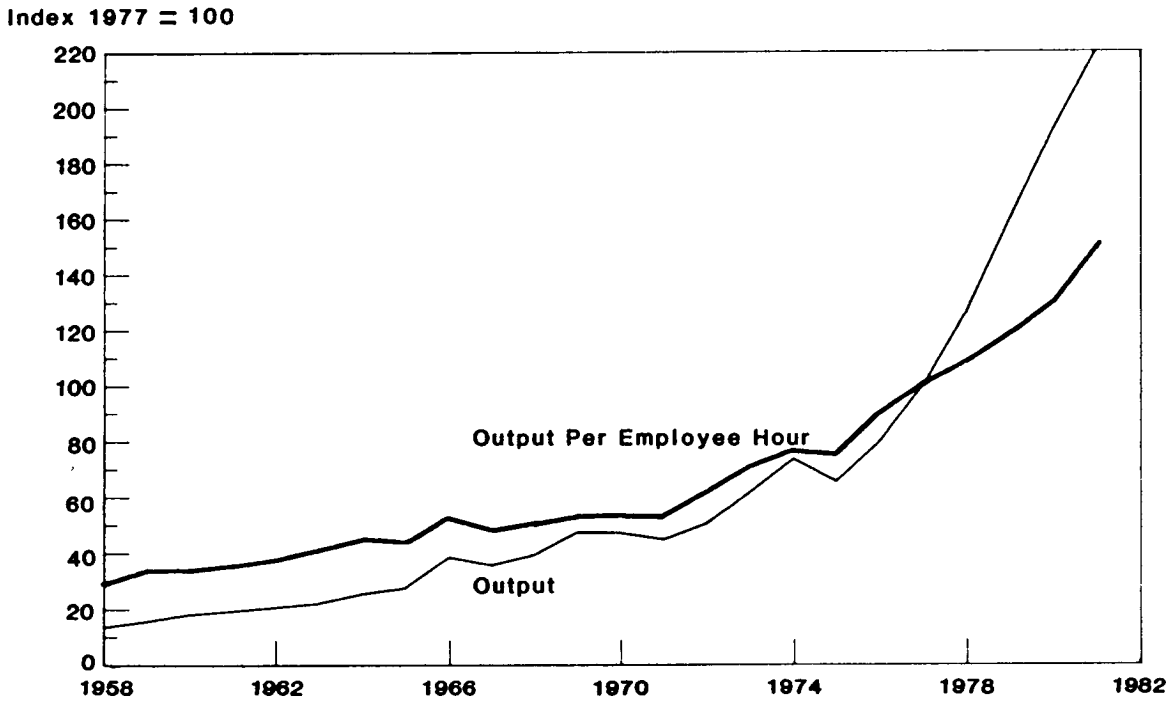
In 1980, the office, computing, and accounting equipment subdivision contributed 18% of the value of shipments and 18% of the value added for the machinery except electrical subsector. This industry subdivision has shown an impressive growth rate, despite the recession and the recent decline in foreign exports. From 1972 to 1982, the annual growth rate of the computing industry shipments was 8.8% (1972 $); the growth rate has increased to 11.5% per year since 1982.

Tables 1-16 and 1-17 portray the business and structural profiles of the computing and accounting equipment subdivision. Employment has grown over 100% since 1972. The annual growth rate in employment from 1972 to 1982 was around 7%; since 1982, this growth rate slowed to approximately 3% per year. Labor productivity, i.e., output per employee hour, increased at an annual rate of about 4.8% from 1958 to 1971; it expanded to an annual rate of 10.9% from 1971 to 1981. This labor productivity growth rate has been very steady, with only one minor downturn in 1967.

TABLE 1-16

BUSINESS PROFILE OF THE OFFICE, COMPUTING, AND ACCOUNTING MACHINERY INDUSTRY (SIC 357)

SHIPMENTS (BILLION $)	1972	1977	1979	1981	EST. 1982	EST. 1983	EST. 1984
CURRENT $	8.6	16.8	26.1	37.8	41.5	47.2	53.5
1972 $	8.6	12.0	15.9	19.4	20.0	22.4	24.9
TOTAL EMPLOYEMENT (THOUSANDS)	208.5	259.2	347.3	387.5	400.6	410.8	423.2



Source: Unpublished BLS Data

NEW CAPITAL EXPENDITURES CURRENT $, BILLIONS	1980	1981
	2.00	2.35

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK

TABLE 1-17

STRUCTURAL PROFILE OF THE OFFICE, COMPUTING, & ACCOUNTING MACHINERY INDUSTRY (SIC 357)

ESTABLISHMENTS (1977) (CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	702
INTERMEDIATE (20-1000)	550
LARGE (>1000)	61
TOTAL (1149 COMPANIES)	1313

LEADING FIRMS (1983)

NAME	DOMESTICALLY GENERATED SALES ($ BILLION)
IBM	23.30
SPERRY CORP.	1.87
DIGITAL EQUIPMENT CORP.	1.83
BURROUGHS CORP.	1.75
CONTROL DATA	1.71
HEWLETT PACKARD	1.68
HONEYWELL	1.23
MOORE CORP.	1.22
PITNEY-BOWES	1.21
WANG LABORATORIES	1.11

PRODUCTION COST DISTRIBUTION, 1977	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
	8.2%	15.2%	39.6%	4.2%	32.8%

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984

TABLE 1-18

CONSTRAINT PROFILE OF THE U.S. OFFICE, COMPUTING, & ACCOUNTING EQUIPMENT AND SUPPLIES INDUSTRY

CONSTRAINT	PRINCIPLE IMPACT
FEDERAL CLEAN AIR AND WATER ACT	REGULATION FOR DISPOSAL OF SOLVENTS USED IN SEMICONDUCTOR WAFER WASHING.
U.S. ECONOMIC STRENGTH	STRONG DOLLAR AND SLUGGISH FOREIGN ECONOMIES HAMPER U.S. INDUSTRY MARKET GROWTH.
CONTINUED DEREGULATION OF TELECOMMUNICATIONS INDUSTRY	THE BROADENING OF PRODUCT LINES TO REMAIN COMPETITIVE IN THE COMPUTER/COMMUNICATIONS INDUSTRY.
FOREIGN GOVERNMENT SPONSORED INCENTIVES (CORPORATE TAX HOLIDAYS) AND CHEAP ASIAN LABOR	THE MOVING OF ASSEMBLY AND PRODUCTION PLANTS OVERSEAS.
COMMON CORPORATE STRUCTURE IS HORIZONTAL INTEGRATION	ORDERS BACKLOGS, AND PARTS BOTTLENECKS CAUSED BY SUBCONTRACTOR LAGS.

The majority of the establishments in this subdivision (53% in 1977) employ less than twenty persons. However, its top ten firms accounted for 88% of the industry's domestically generated sales in 1983. Thus this industry is highly concentrated and very competitive. The top company, IBM, accounted for about 56% of domestically generated sales. Because of this dominance maintained by IBM, the computer sales of the other companies within the subdivision are significantly affected by their compatibility with IBM equipment. IBM's vertically integrated structure (i.e., the manufacturer produces the entire product and does all assembly) also enables the company to compete with Japanese computer manufacturers. Other companies have difficulties meeting orders and are therefore less competitive because of snags in productivity resulting from the limited number of components manufactured by each company.

Another reason for IBM's success in maintaining its dominant position in U.S. and world markets is the company's developmental approach and huge market inertia. IBM identifies a market or business area and then sets goals for meeting the needs of this market. Thus, IBM is able to offer results that businesses want. IBM's innovations are in the area of computer functions instead of computer capabilities, thus IBM sacrifices incorporating new technologies in its machines for performance of operation. Historically, IBM has maintained a record for supermaintenance--i.e., the computer system is brought up to full capacity fast--especially in the 1960s when big ticket, off-the-shelf systems were not as available as is the case currently. IBM has thus developed a huge market inertia based on its reputation.

The production cost distribution for the office, computing and accounting subdivision is detailed in Table 1-17. Nearly 40% of its production costs are materials costs. Over 40% of materials costs are spent on parts and attachments specifically designed for computers--semiconductors, resistors, capacitors, and other electronic-type components account for 18% of these

materials costs. Capital costs amount to about 33% of production costs. Labor costs are about 23% of production costs. Since manufacturing labor accounts for 8% of production costs, companies are still finding it profitable to move assembly plants overseas to take advantage of cheaper unskilled labor.

The chief constraints affecting this industry are summarized in Table 1-18.

Structural changes in the computer, office, and accounting equipment manufacturing industry are mainly technology driven. As technology improves and price drops result, new markets emerge and expand. Advanced technology is forcing changes in all aspects of this industry; from component manufacturers unable to compete economically on the small scale to large system manufacturers that are giving up custom designs and specialized subsystems in favor of utilizing cheaper components from outside suppliers. Except for the first two entries in Table 1-18, both concerning regulatory or economic constraints, all of the other constraints are, to a large extent, the result of continued advances in technology.

Competitive Issues Affecting the Office, Computing, and Accounting Equipment Industry

Exports of U.S. produced computer equipment have been growing 20% annually since 1972, while exports of office and accounting machinery grew 12% per year during this same period. The majority of computer exports (54%) are destined for Western European markets. These computer exports should increase by 20% to over $12 billion in 1984, if the U.S. and European economies continue their current recovery. Exports of office equipment grew at an annual rate of 19% from 1972 to 1981; from 1981 to 1983, they declined by approximately 23% to $487 million. A 10% rise in office equipment exports to $535 million is forecast for 1984.

Japan, Hong Kong, Taiwan, Singapore, and Korea are rapidly expanding their shares of the U.S. imported computer market. U.S. imports of office and computer equipment rose at an annual rate of 28% from 1972 to 1983, and are projected to rise another 50% in 1984. During 1983, imports of computers from Japan rose by 113%; imports from Korea rose 53%; imports from Taiwan rose 97%; imports from Singapore rose 700%; imports from Hong Kong rose 157%. Such trends resulted from the strong U.S. dollar and from certain characteristics within these countries favorable to industry exports.

Asian countries are able to penetrate and compete favorably in the U.S. domestic market because of their cheaper labor costs, favorable government subsidies and tax policies, integrated government-university-industry targeting of profitable and expanding markets, and the level of vertical integration prevalent in their corporate structure. Japan's Ministry of International Trade and Industry (MITI) is organized to identify and set up strategies to exploit potentially profitable markets and industries. Three markets that the Japanese hope to enter and dominate in the computer industry are supercomputers, superminicomputers, and portable computers.

The U.S. supercomputer market is not large; 1983 sales for 28 supercomputers, priced from $5-15 million, generated $230 million in revenues. In 1984, vendors expect to ship 35 supercomputer systems valued at $310 million. Future market growth may exceed the current 25% annual growth rate. The major market for supercomputers is the government; especially government scientific agencies, national research labs, and the Department of Defense. Given the modeling and analysis capabilities of supercomputers, it is reasonable to assume that private industry will be purchasing an increasingly large share of new machines.

Japan is moving rapidly to expand the processing capabilities, size, and speed of its supercomputers through government

subsidized research efforts. Japan's foreign market for supercomputers is currently restricted to Europe, but is expected to soon gain a share of the U.S. domestic market.

There are two strategic values of a strong domestic supercomputer industry: first, the advanced technologies applied to these machines quickly permeate the entire computer industry; second, some key design and development manipulations are performable only on supercomputers. Thus, a great deal of national scientific strength and innovation relies on the continued advancement of the domestic supercomputer industry.

The U.S. government, through agencies such as the National Science Foundation (NSF), the Departments of Energy and Defense, and the Defense Advanced Research Projects Agency (DARPA), is providing over $60 million for supercomputer research in 1984. Total government sponsored R&D could grow to over $1 billion within the next five years. Supercomputer manufacturers are in turn putting 20% of their gross revenues back into R&D.

Japan is spending considerably more on advanced supercomputer designs than the U.S. For example, one joint Japanese government and industry project is to develop a supercomputer capable of performing 10 billion floating point operations per second (gigaflops) by the end of the 1980s. Japan's Superspeed Project is a $200 million effort to produce a 1 gigaflop machine by 1989. Another Japanese initiative is the 10 year, $500 million Fifth Generation Project, which is devoted to artificial intelligence R&D.

High performance superminicomputers are in much more demand than supercomputers in the U.S., largely because of the amount of CAD/CAM software available for these machines. U.S. universities have continued to train users on VAX-sized systems; the business processing market is also very well suited to the incorporation of superminicomputers. Worldwide shipments of superminicomputers

were estimated at $2 billion in 1983, with annual growth predicted at 30% over the next five years. Superminicomputer sales growth estimates of 80% to 90% per annum are common. Six U.S. firms currently hold the majority of this world market, but the Japanese are beginning to expand their operations.

The portable computer industry is mainly comprised of small, recently started companies. Sales have been climbing rapidly since the first portable microcomputer was introduced in 1981. In 1982, portable sales reached $294 million, while 1983 sales are predicted to top $900 million (a one year increase of over 300%). Future Computing Inc. predicts the world market for this industry to be $5.7 billion by 1987. The market for portables and transportables is growing so fast that industry observers expect all of the major office equipment suppliers to enter it with their own models.

Cost and compatability are more important for new product sales that portability. The top price that will be paid for a portable system is $3000, while some company products are selling for between $800 and $1800. Lower Japanese labor costs combined with subsidized market penetration, suggest that the Japanese products will not only compete with U.S. made superminicomputers, but may erode U.S. domestic profit margins.

Another major area of computer technology that is rapidly moving offshore is computer support equipment and peripherals. Singapore has realized a significant market share in this technology because of its emergence as a major center for the assembly of magnetic disk drives. Japanese manufacturers of disk drives are seeking the development of standards in order to compete more effectively on the world market.

The U.S. incurred a $100 million trade deficit in computer equipment purchases with Taiwan in 1983. In addition, Japanese computer equipment has been in continued demand, even during the

most recent recession, because of their competitively priced printers.

The result of the continued growth in foreign shares of the U.S. domestic market is a declining positive balance of trade in computers and office equipment. From 1972 to 1981, the positive balance of trade grew 21.8% annually to a peak of $6.75 billion; since 1981, it has dropped at an annual rate of 8.7%, to an estimated $5.1 billion in 1984. Table 1-19 shows the trade balances in U.S. computer equipment by regions. In 1982, the U.S. registered its first trade deficit in computers and equipment with Japan. The 1983 trade deficit with the Asian suppliers climbed to over $1 billion. This trend is expected to continue as more U.S. parts suppliers continue to move offshore.

Productivity in the Office, Computing, and Accounting Equipment Industry

The figure in Table 1-16, drawn from unpublished BLS data, shows the steady rise in labor productivity (output per employee hour), while Table 1-16 depicts average production costs for this industry in recent years. While materials costs account for nearly 40% of production costs, foreign suppliers of parts and attachments specifically designed for computers are forcing these prices to fall as they grow increasingly more competitive with U.S. domestic parts suppliers. Capital costs amount to 33% of production costs. These include new computer-design tools utilizing supercomputers, recent environmental controls mechanisms for ultraclean fabrication rooms and for cleaning solvent disposal, and R&D efforts. Labor accounts for around 23% of production costs. Manufacturing labor accounts for only 35% of total labor costs; the other 65% is spent in designing and engineering.

Role of Technology in the Long-Term Strategic Outlook

The office, computing, and accounting equipment subdivision is a "sunrise" industry. Market growth for the industry is 25 to

TABLE 1-19

TRADE BALANCES IN U.S. COMPUTER EQUIPMENT AND PARTS, BY REGION AND SELECTED COUNTRIES
($ MILLION)

	1978	1982	1983[b]
WESTERN EUROPE	2,133	4,362	5,199
NORTH & SOUTH AMERICA	597	1,228	1,202
ASIA & PACIFIC	249	543	330
SINGAPORE	8	47	-100
FAR EAST	208	79	-1,069
JAPAN	137	-32	-890
HONG KONG	18	37	-60
TAIWAN	30	22	-100
AFRICA & NEAR EAST	130	429	508
EASTERN EUROPE	55	23	30
TOTAL[a]	3,373	6,665	6,200

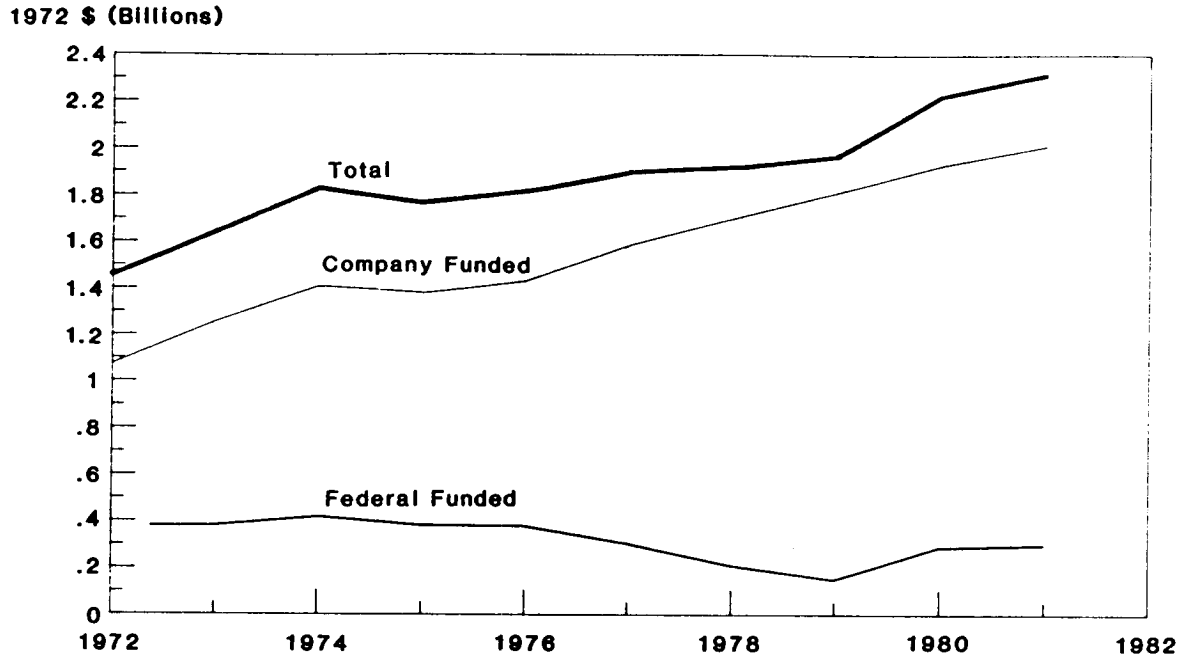
[a] SUMMING OF REGIONAL FIGURES MAY NOT MATCH THE WORLD TOTAL DUE TO ROUNDING.
[b] ESTIMATED BY BIE.

SOURCE: DERIVED BY BIE FROM U.S. DOC/BOC DATA.

30% per year. The constant dollar value of R&D expenditures has steadily risen by 4.7% per year since 1972; the company funded portion of R&D expenditures rose 6.5% over the same period, see Figure 1-5. While recent recession severely restricted patent output, patent activity has climbed rapidly following the recession, see Figure 1-6. Computing machine capabilities are rapidly expanding, with the office machinery subdivision responding to advances in microcomputers and printer technology. New markets are also appearing (such as electronic mail) that displace older technologies with faster and more sophisticated methods. The merging of the computer and communications markets should also provide ample room for sustained growth in shipments through the next decades.

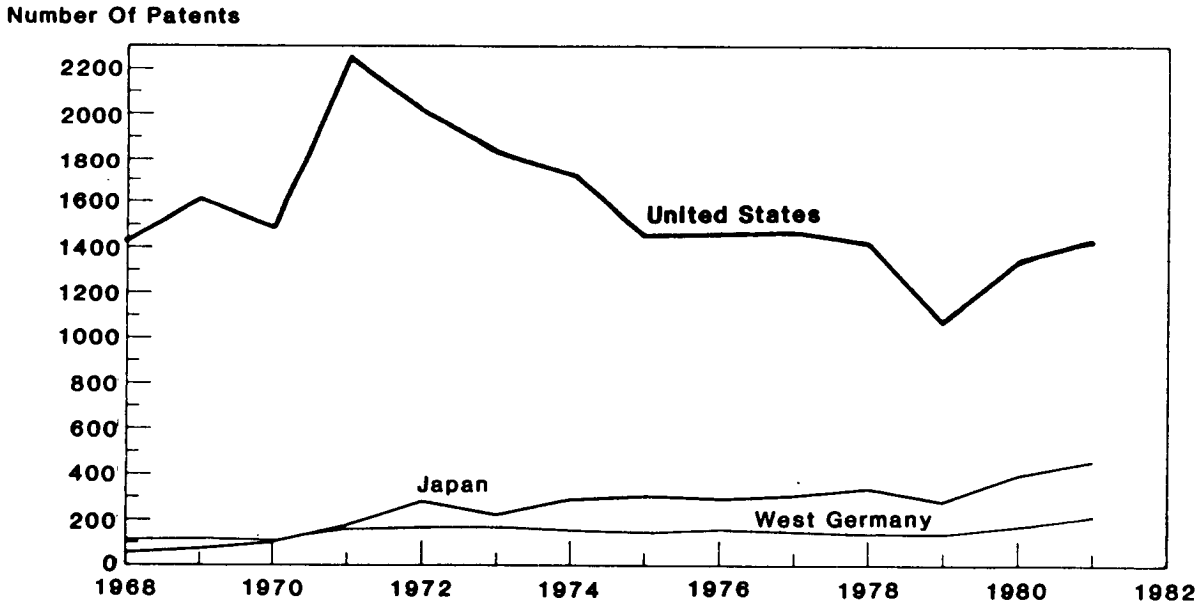
Historically, the cost of computing capability has been and is decreasing at an annual rate of 0.8%, while the growth rate in computing power (in terms of operations per second) increases by approximately one order of magnitude every five years. Grosch's law states that the cost of computer functions drops proportionally to the square root of the power. The decreasing cost of increased computing capability is pictured in Figure 1-7. The historical increase in computing speed is pictured in Figure 1-8.

Computers accounted for over 90% of shipments for the office, computing and accounting equipment subdivision. Advances in computer technology can be sudivided into three categories: structure, performance, and function. These categories establish a hierarchy of computer components, from an individual component level to an overall system level. Structure refers to the hardware technology and architecture utilized in the computer. Performance measures the speed and capacity of the computer or its components. Function represents the specific task for which the computer is designed.



Source: National Science Foundation

Figure 1-5. Research and Development Expenditures for the Office, Computing, and Accounting Equipment Industry



Source: Patent Output Of U.S. Industry Compiled By The National Science Foundation

Figure 1-6. Patent Activity by Year for Leading Countries Manufacturing Office, Computing, and Accounting Equipment and Supplies

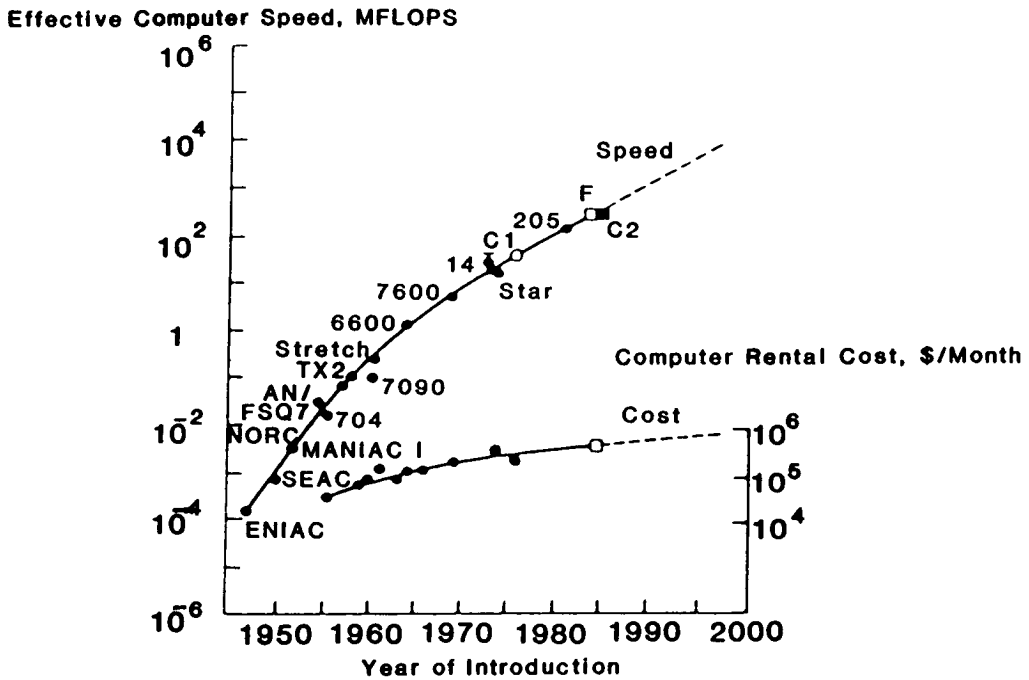


Figure 1-7. Past Growth and Future Projections for Computer Speed and Costs

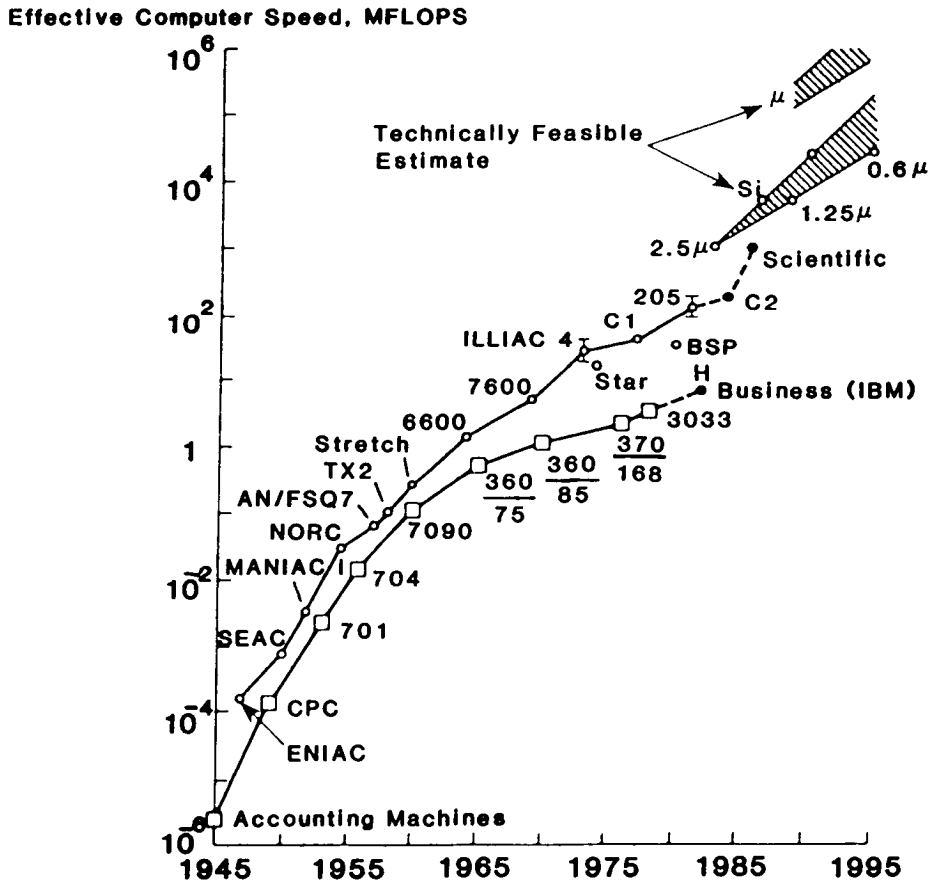


Figure 1-8. Computer Speed as a Function of Time

Advances in Computer Structure

The structure of the computer is rapidly evolving beyond the original Von Neumann architecture. Conventional Von Neumann organization centers around a control and logic unit labeled the central processing unit (CPU). Programs and data are stored in a separate memory that is accessible to the CPU. Program steps are retrieved from memory and executed sequentially. This is an example of control flow architecture, in which a sequential counter points to the next instruction to be executed. The basic organization is entitled a single instruction, single data stream organization (SISD).

Solid state circuits are approaching their physical limits for performance. In the range of one billion operations per second (GOPS), the total signal path for each operation cannot exceed eleven inches. For 3GOPS performance, the total signal path must be less than four inches. Device fabrication and interconnection techniques are not anticipated to go beyond this limit. Thus, the contemporary Von Neumann architecture is clearly inadequate for performance beyond 1 to 3GOPS.

The parallel processor organization is designed to improve the operations per second performed by a computer. In this organization, multiple processors replace the CPU. These processors are capable of executing a single instruction on multiple data streams (SIMD), multiple instructions on a single data stream (MISD), and multiple instructions on multiple data streams (MIMD). Programming parallel processors requires a highly structured and organized, low-entropy code.

The supercomputer is defined as the most powerful computer available in terms of speed and capacity. Current supercomputer technology is based on pipeline processors (MISD) and vector processors (SIMD). Pipeline processing sets up a sequence of steps to perform each instruction in separate processors. The

computer acts like an assembly line: Each processor can work independently so that multiple steps--one from each of several instructions--are performed simultaneously. Vector processing uses multiple processors to perform the same instruction step simultaneously on multiple arrays of data. While multiprocessor technology is just one part of the design technology integrated into current supercomputers, it represents the strategy most likely to produce the next quantum leap in supercomputer performance.

MIMD technology is difficult to implement, but is a powerful tool for increasing computer capability. This technology involves organizing the computer to perform most efficiently by optimizing its utilization of multiple processors. Although MIMD seems to connote a computer consisting of several independent computers, the multiprocessors are all controlled to perform optimally. An example of this organization is data flow architecture. While a typical Von Neumann organization utilizes a control flow architecture, in which the next instruction in sequence is given the highest priority for CPU space, data flow architecture utilizes a processor to assess which operations require which data, and then to perform these operations as soon as the data become available.

Although the speed, capacity, and capabilities of computers have expanded nearly to the point where conventional Von Neumann architecture's limitations are discernable, most software being written is still Von Neumann-oriented. There has been no major progress in terms of simplifying rigidly structured languages since 1960. There are major improvements to be made in the field of software, with the eventual goal of self-programming, self-adaptive computer code.

Much computer structure improvement is based on advances in actual hardware. For example, a computer's speed is dependent on how densely packed active devices are, and on the material that

comprises these devices. Some densely packed hardware configurations are very large scale integration (VLSI), very high speed integrated circuits (VHSIC), and wafer scale integration (WSI). The size of active devices has shrunk faster than the size of interconnections; thus, large chip areas for interconnections are sources of delays as well as heat sources. All new supercomputers require state-of-the-art heat removal devices because of the power generated by large scale circuits and also to enable superconductivity to further enhance signal speed, provided applied research in superconducting computers is fruitful.

Human interface technology is another hardware area in which much research is being conducted. The goal is to develop an interface capable of understanding and operating based on human speech instructions at the conversational level from a person with a 10,000 word vocabulary by 1990. Computer hardware advances and projected dates of application are summarized in Table 1-20.

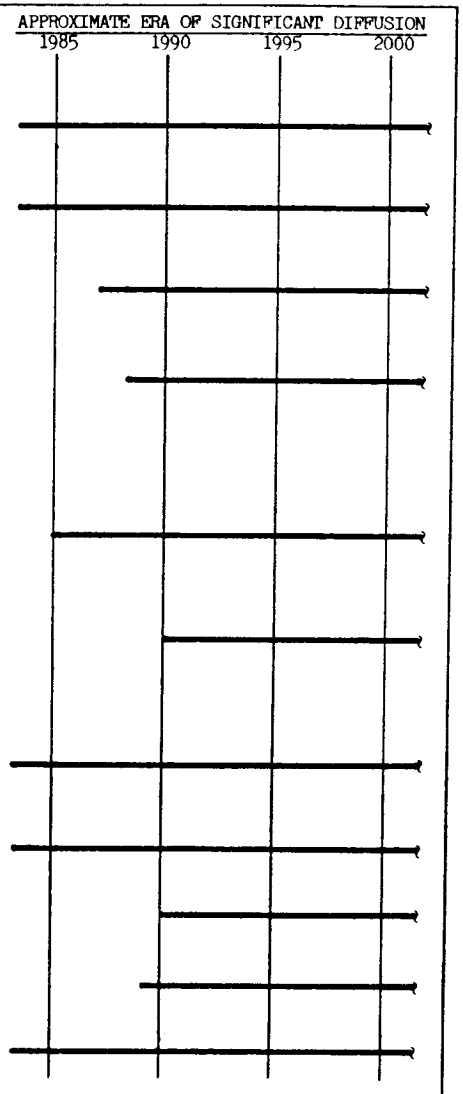
Advances in Computer Performance

Two examples of VHSI circuits are gallium arsenide ICs and complementary metal oxide semiconductor (CMOS) components. Gallium arsenide (GaAs) integrated circuits have switching speeds significantly faster than 300 picoseconds, while requiring ten times less power than comparable silicon ICs. Components typically fabricated with GaAs are called metal semiconductor field effect transistors (MSFETs), and are either depletion or enhancement mode devices. Depletion mode GaAs MSFETs are quicker but require more power than enhancement mode devices. Cray Research is the largest U.S. supercomputer manufacturer, and their machines will incorporate GaAs technology. The next largest U.S. supercomputer manufacturer, ETA Systems, intends to employ CMOS technology instead of GaAs. CMOS ICs are not as fast as GaAs ICs but they dissipate less heat and can be packed much closer, thus

TABLE 1-20

COMPUTER STRUCTURE TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT
PROCESSOR ARCHITECTURE		
• SINGLE INSTRUCTION SINGLE DATA STREAM (SISD)	SEQUENTIAL PROCESSOR (VON NEUMANN ARCHITECTURE).	MOST WIDELY USED PROCESSOR ARCHITURE, BUT MAXIMUM PERFORMANCE IS 3 BILLION OPERATIONS PER SECOND.
• SINGLE INSTRUCTION MULTIPLE DATA STREAM (SIMD)	VECTOR OR ARRAY PROCESSORS PROCESSORS.	CAPABLE OF HANDLING LARGE PARALLEL PROCESSING TASKS, BUT REQUIRES DATA TO BE STRUCTURED IN DENSE ARRAYS.
• MULTIPLE INSTRUCTION SINGLE DATA STREAM (MISD)	PIPELINE PROCESSORS.	HIGH SPEED PROCESSING OF SEQUENTIAL DATA ARRAYS THROUGH SHARED PROCESSING.
• MULTIPLE INSTRUCTION MULTIPLE DATA STREAM (MIMD)	MULTIPLE PROCESSING UNITS COMBINED IN A SINGLE SYSTEM WITH ONE OR MORE CONTROLLING INSTRUCTION INTERPRETATION UNITS.	LARGE PIPELINE PROCESSING NEEDS CAN BE CONTROL OR DATA DRIVEN-SOME DEGREE OF ASSOCIATIVE PROCESSING.
CONTROL MECHANISM		
• CONTROL DRIVEN EXECUTION	INSTRUCTION IS SELECTED BY THE CONTROL FLOW-SEQUENTIAL OPERATION USING A SINGLE PROCESSING ELEMENT-ESSENTIALLY OPTIMIZED VON NEUMANN PERFORMANCE.	CONTROL MECHANISM FOR OPTIMUM VON NEUMANN PERFORMANCE.
• DATA DRIVEN EXECUTION	INSTRUCTION IS EXECUTED WHEN SOME COMBINATION OF ITS ARGUMENTS BECOMES AVAILABLE.	CONTROL MECHANISM TO IMPLEMENT AND OPTIMIZE PARALLEL PROCESSING.
HARDWARE		
• GALLIUM ARSENIDE CIRCUITS (GaAs)	FAST, LOW POWER GaAs CIRCUITS CAPABLE OF DENSER PACKING THAN SILICON CIRCUITS.	SUPERSEDES SILICON FOR CIRCUIT FABRICATION.
• COMPLEMENTARY METAL OXIDE SEMICONDUCTOR CIRCUITS (CMOS)	FAST, LOW POWER CIRCUITS.	SUPERSEDES SILICON FOR CIRCUIT FABRICATION.
• CRYROGENIC JOSEPHSON JUNCTIONS	SUPERCONDUCTING SWITCHING CIRCUITS.	VERY FAST, LOW POWER CIRCUITS.
• OPTOELECTRIC TRANSMISSION/DETECTION DEVICES	HIGH SPEED TRANSMISSION LINKS UTILIZING FIBER OPTICS.	INTERFACE DIGITAL ELECTRONICS WITH OPTIC FIBER TRANSMISSION LINKS FOR HIGH SPEED CIRCUITS.
• FLAT PANEL CATHODE RAY TUBE (CRT)	HIGH RESOLUTION FLAT PANEL DISPLAY.	ADVANCES THE RESOLUTION OF VISUAL INTERFACES.



SOURCES: COMPUTER DESIGN, SEPT. 1984
U.S. DOC/NBS

reducing interconnection distance. Although large scale integration of CMOS components gives an order of magnitude density improvement over GaAs, this cannot provide an order of magnitude speed improvement over enhancement mode GaAs MSFETs. Opinion is divided over trading speed for circuit density.

Wafer scale integration (WSI) is an example of VLSI taken to its extreme. WSI superchips range in size from two to eight inches in diameter and can hold the equivalent of from 25 to 100 Intel 8086 microprocessors. WSI offers several advantages over integrating circuits over much smaller chips and interconnecting them. First, fewer pins protrude from a packaged circuit to connect it to other packaged circuits, thus improving system reliability. Second, replacing a number of chips on a printed circuit board with one integrated wafer eliminates interchip connections which slow the signal, consume extra power, and introduce noise. Disadvantages of WSI are heat removal and product yield. Some wafers may generate up to 1000 watts of heat. A wafer is too costly to throw away if there are faulty gates or circuits produced on it during manufacture. The material best suited for current WSI manufacture is CMOS, while GaAs is also attractive and may justify its cost in comparison to GaAs ICs. The first commercial domestic WSI products in the U.S. will probably be memory systems, which are already available in Japan. WSI logic systems may be the next to follow memory systems, especially if three-dimensional stacking of wafers becomes a supercomputer organization.

Advances in Computer Functions

A computer's application is typically specified at the time of programming, while even specialized computing devices have new tasks and applications found for them after their introduction. Computer applications are generally separated into two broad categories: scientific computations and application, and business computations. Typical scientific applications are real-time

controls, digital switching for communications, and signal processing. The distinction between most scientific and business computations is that scientific computations involve numerical calculations requiring speed and numerical accuracy, while business computations usually involve character oriented instructions and symbolic manipulations. Artificial intelligence represents a synergism between business and scientific computing based on symbolic computations.

Currently, there are a limited number of scientific applications for supercomputers, including weather prediction and modeling (computational fluid dynamics), seismic modeling, nuclear engineering (Monte Carlo calculation, for example), ballistic missile defense, and applications requiring a large amount of parallel computations. Three primary commercial industries targeted for supercomputer sales are the aerospace, automative, and oil and gas exploration industries. Between 1976 and 1983, U.S. suppliers shipped less than 100 supercomputers, three of which have been installed in U.S. universities. Thus the market is still limited by a lack of trained users. Japanese suppliers hope to install 100 of their supercomputers over the next five years.

Conclusion

The demand for computing equipment is growing by 25 to 30% annually. At the same time, there is a increasing synergy between computers and communication equipment. New uses for computers are constantly being discovered and developed. Thus, the office, computing, and accounting equipment subdivision is classified as a "sunrise" industry. The only constraints on even more brisk growth are the long product lifespans, and the desire of the user to have future products that are compatible with current or obsolete systems.

General purpose computers are incorporating new hardware technologies and configurations, but these evolutions are limited to minor changes in order to minimize software conversions. Computer structure is becoming increasingly more modular, which may be a relatively inefficient use of hardware due to redundancy. It is much cheaper to use mass-produced microprocessor modules instead of custom designed integrated circuits, which are expensive to design. By 1987, processing modules should have absorbed most of the system management functions currently performed by operating systems.

The primary thrusts of developing technology that offer significant improvement in processing rates are faster componentry and parallel processing. VLSI technology offers improvements in processing speed by up to a factor of three in the near future (1985). Wafer scale integration also offers the benefits of VLSI, but is used primarily for memory devices because of the difficulty encountered in producing GaAs and CMOS integrated circuits are not only faster but, since they dissipate less power (heat), they may be more densely packed, which cuts down interconnection distances and increases component speed. The physical limits as far as computing speed are beign approached for Von Neumann computers, thus parallel processing offers virtually the only route for speedup as a result of modifications of system architecture.

The primary need of the office, computing, and accounting equipment subdivision is the establishment of industry-wide standards. This is especially true for the increasingly modular structure of computers. By 1990, the user should never have to replace a computing system in its entirety. Instead, expansion modules will be added to tailor the system to the user's needs. Similarly, programs and databases must be machine-independent to facilitate transfer from machine to machine.

B.2 "TRANSPORTATION EQUIPMENT" (SIC 37)

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B.2 "TRANSPORTATION EQUIPMENT" (SIC 37)

The transportation equipment subsector, SIC 37, includes establishments engaged in manufacturing equipment for transportation of passengers and cargo by land, air and water. The subsector accounted (in value added) for 9.9% of the manufacturing sector's contribution to GDP in 1980. Second only to Machinery except Electrical, SIC 35, the subsector is characterized by:

- A high degree of fragmentation. Out of a total of approximately 10,000 establishments, 6,500 employed fewer than 20 persons (1977).

- A labor productivity of $24,224 per employee year or $12.62 per employee hour (1980, 1972 $), ranking this subsector ninth among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 0.5%/year from 1972 to 1980 ranks this subsector fifteenth. The labor productivity for the comparable Japanese subsector was $13,875 per employee year or $7.23 per employee hour (1980, 1972 $), ranking this subsector fifth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 4.2%/year from 1972 to 1980, ranking this subsector eighteenth.

- A somewhat less intensive capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $15,032 in total assets per worker, ranking ninth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $2,517 per employee (1980, 1972 $) ranking seventh in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment was 0.63 (1981).

- An aggressive R&D program. For the subsector as a whole, R&D expenditures amounted to $8 billion (1980, 1972 $), ranking it first among the 20 manufacturing subsectors. R&D expenditures were equivalent to 18.7% of the value added by the subsector in 1980.

Table 2-1 shows the major products of each component of the transportation equipment subsector, ranked in descending order in terms of share of the subsector's contribution to GDP in 1980. Table 2-2 characterizes their principal economic measures.

As shown, two subdivisions--Motor Vehicles and Equipment (SIC 371) and Aircraft and Parts (SIC 372)--accounted for 76% of the subsector's output in 1980. Another subdivision (SIC 376), Guided Missiles, Space Vehicles and Parts, which accounted for an additional 10%, is important because of its use of the most advanced technology. In assessing long-term technology needs, we selected these three subdivisions for detailed analysis. These are described in Volume II, Section B.2. The analysis of the motor vehicle subdivision (SIC 371) is described following.

B.2.1 MOTOR VEHICLES (SIC 371)

This subdivision includes establishments that manufacture completed motor vehicles and motor vehicle parts, but does not include establishments that solely manufacture motor vehicle parts.

In 1977, the last "normal" year in the recent past, the motor vehicle subdivision (SIC 371) accounted for 51% of the value added value and 65% of the shipments in the motor vehicle and equipment industry. The period following 1977 marked a crisis in the industry. Strong import competition, shifts in consumer preferences, and poor sales due to economic recession caused the years 1980 and 1981 to be the bleakest in the industry's history. Although the industry has made a significant recovery in 1983 and 1984, the long-term outlook is uncertain.

TABLE 2-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE TRANSPORTATION EQUIPMENT INDUSTRY (SIC 37) AND RELATIVE CONTRIBUTION TO TOTAL SUBSECTOR OUTPUT, 1980

SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
371	**MOTOR VEHICLES AND EQUIPMENT** AUTOMOBILES, TRUCKS, COMMERCIAL CARS AND BUSES, SPECIAL PURPOSE MOTOR VEHICLES, MOTOR VEHICLE BODIES AND TRUCK TRAILERS, MOTOR VEHICLE PARTS AND ACCESSORIES.	39.9
372	**AIRCRAFT AND PARTS** AIRCRAFT, AIRCRAFT ENGINES AND PARTS, AUXILIARY EQUIPMENT AND ASSOCIATED R&D.	36.1
376	**GUIDED MISSILES, SPACE VEHICLES AND PARTS** GUIDED MISSILES, SPACE VEHICLES, SPACE PROPULSION UNITS, PARTS AND AUXILIARY EQUIPMENT AND ASSOCIATED R&D.	9.6
373	**SHIP AND BOAT BUILDING AND REPAIR** SHIPS, BOATS, BARGES AND LIGHTERS.	8.2
374	**RAILROAD EQUIPMENT** LOCOMOTIVES, RAILROAD, STREET AND RAPID TRANSIT CARS AND CAR EQUIPMENT.	4.2
379	**MISCELLANEOUS TRANSPORTATION EQUIPMENT** TRAVEL TRAILERS AND ATTACHMENTS FOR PICK-UP TRUCKS AND MOTOR HOMES, MILITARY TANKS AND OTHER TRANSPORTATION EQUIPMENT.	1.4
375	**MOTORCYCLES, BICYCLES, AND PARTS** MOTORCYCLES, BICYCLES AND ASSOCIATED PARTS AND EQUIPMENT.	0.6
37	ALL TRANSPORTATION EQUIPMENT	100.0

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972

TABLE 2-2

SUBDIVISIONS AND CHARACTERIZATION OF THE TRANSPORTATION EQUIPMENT INDUSTRY (SIC 37), 1980, IN 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	EMPLOYEES (1000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL TRANSPORTATION EQUIP. (37)	100	1772.1	10,176	6,518	1,561	15,032	2,517	24,224
MOTOR VEHICLES AND EQUIP. (371)	40	714.3	4,234	2,526	802	23,718	4,274	23,949
AIRCRAFT AND PARTS (372)	36	580.5	1,173	624	253	9,640	1,562	26,669
SHIP AND BOAT BUILDING AND REPAIR (373)	8	218.6	2,795	2,059	261	8,294	845	16,071
RAILROAD EQUIP. (374)	4	65.2	201	83	66	11,101	1,442	27,654
MOTORCYCLES, BICYCLES AND PARTS (375)	1	15.2	350	287	19	8,735	811	17,519
GUIDED MISSILES, SPACE VEHICLES AND PARTS (376)	10	140.7	109	18	64	8,459	1,217	29,176
MISCELLANEOUS	1	37.6	1,314	921	96	6,386	1,015	17,342

[a] 1977

SOURCE: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981

The subdivision's historical and current posture is summarized in Tables 2-3 and 2-4, which portray the industry's business and structural profiles, respectively. Table 2-3 shows that, expressed in constant 1972 dollars, industry shipments have increased only 13% in eleven years, from $42.9 billion in 1972 to $48.8 billion in 1983. Because of the recent economic recovery, the 1984 forecast is for shipments of $54.2 billion (in 1972 $), an increase of 11.1% over 1983. Employment has steadily declined, falling by 22%, from 339,000 in 1972 to 265,000 in 1983. Labor productivity, i.e., output per employee hour, rose fairly steadily until 1977. A stasis was experienced during the next three years, currently being followed by an upward swing.

Table 2-4 shows that the motor vehicle industry is dominated by four firms, comprising 14% of the subdivision's establishments and accounting for approximately 97% of the output. The remaining 278 establishments are operated by 250 companies that manufacture truck tractors and specialty vehicles (such as stretch limousines, replica antique cars, and limited production sports cars). Of these establishments, 203 or 63% have fewer than 20 employees.

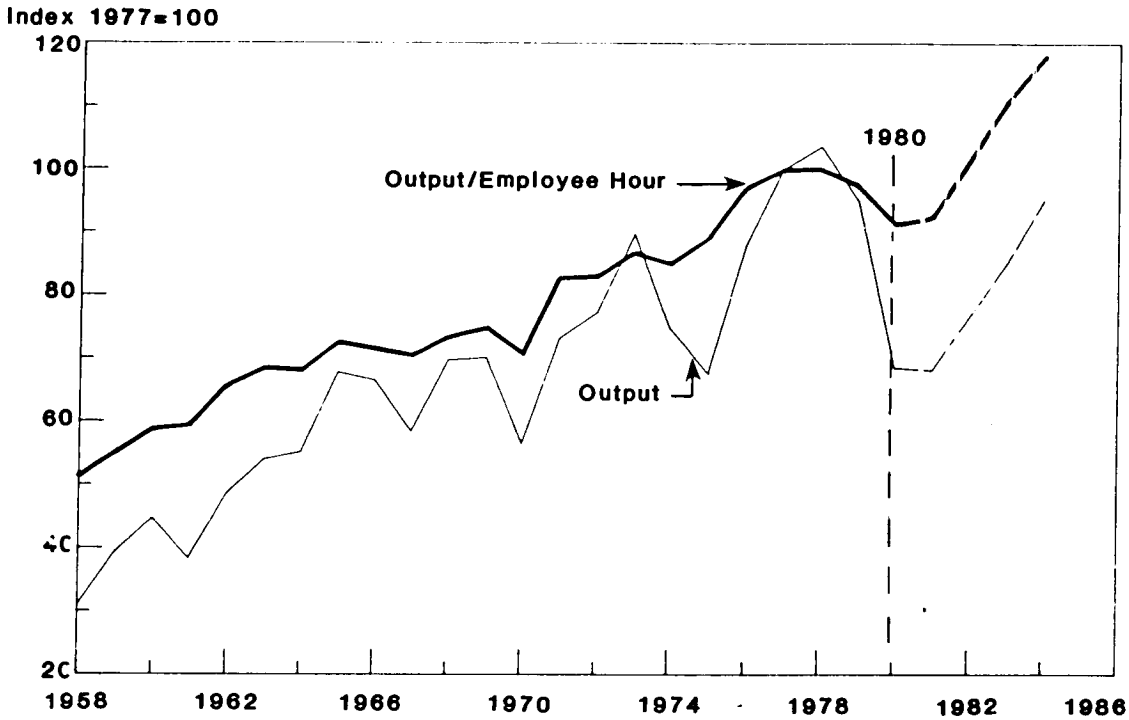
As shown in Table 2-4, the cost of the finished product is dominated by the cost of input materials (75%). Importantly, manufacturing labor represents only 7% of total costs and is expected to shrink as greater levels of automation are adopted.

A major category of input materials consist of manufactured parts from domestic and foreign manufacturers. They range from electronic parts to bumpers, batteries and engines. Precise data on the composition and costs of these input materials are considered proprietary by the industry, and are not officially available. Pertinent data derived from the BLS 1972 Input-Output Table are shown in Figure 2-1. The most costly input material, accounting for nearly half of the value, is motor vehicle parts. The following basic materials emerge as the major input

TABLE 2-3

BUSINESS PROFILE OF THE
MOTOR VEHICLE INDUSTRY (SIC 371)

	1972	1977	1979	1981	1983	1984 EST
SHIPMENTS (BILLION $)						
CURRENT $	42.9	76.5	85.1	74.3	97.9	120
1972 $	42.9	57.2	54.9	40.5	48.8	54.2
TOTAL EMPLOYMENT (THOUSANDS)	339.2	343.6	398.5	271.9	265.0	275.0



	1978	1982	1983	1984 EST
PLANT CAPACITY UTILIZATION, %	93	53	69	75

NET PROFIT MARGIN AFTER TAXES, % 3.6-5.0

VALUE OF PLANT, 1976, CURRENT $ BILLION 6.8

	1977	1981
NEW CAPITAL EXPENDITURE, CURRENT $ BILLION	1.7	4.7

DEALER INVENTORY, END OF 1983 2.4 MONTHS

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOL/BLS
VALUE-LINE INVESTMENT SURVEY, 1984

TABLE 2-4

STRUCTURAL PROFILE OF THE
MOTOR VEHICLE INDUSTRY (SIC 371)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	203
INTERMEDIATE (20-1000)	53
LARGE (>1000)	66
TOTAL (254 COMPANIES)	322

LEADING FIRMS (1983)

NAME	PERCENT INDUSTRY OUTPUT	NUMBER OF ESTABLISHMENTS
GENERAL MOTORS	58.7	21
FORD MOTOR	22.8	14
CHRYSLER CORP.	13.0	7
AMERICAN MOTORS	3.0	2
TOTAL	97.5	44

PRODUCTION COST DISTRIBUTION, 1977

MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
7%	2%	75%	0.5%	15%

R&D EXPENDITURES (SIC 371)
CURRENT $, BILLION/YEAR

1972	1976
2.0	2.8

RETOOLING EXPENDITURES (SIC 711)
CURRENT $ BILLION

1978-1982
51.0

AVERAGE ANNUAL COST OF AIR POLLUTION CONTROL (ALL SIC 37)
(BILLION $, 1972)

1970-1978	1981-1990
3.05	4.02

PASSENGER CAR PRODUCTION

CAPACITY, MILLION UNITS	1978	1982	1982, % of 1978
TOTAL	10	12	120
SMALL CAR	1.4	3.9	279
FRONT WHEEL DRIVE TRANSAXLE	1.2	3.6	300
4-CYCLINDER ENGINE	1.0	4.2	420
V-8 ENGINE	5.7	3.7	65

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984
EPA: 1984 COST OF CLEAN AIR AND WATER REPORT TO CONGRESS

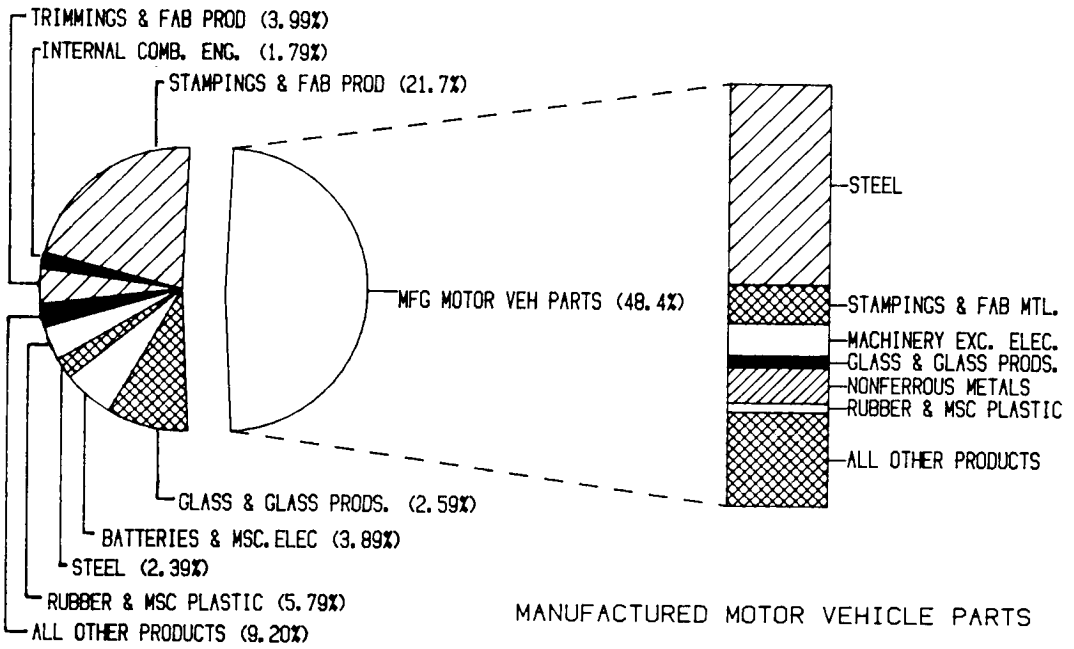


Figure 2-1. Composition of Materials for the Motor Vehicle Industry

materials (with the manufactured motor vehicle parts segmented into its input materials): stampings and other fabricated metal products (26.2%), steel (25.5%), rubber and plastics (6.9%), machinery including engines (5.5%), glass (4.0%), fabricated textile products (4.0%), and batteries and electrical products (3.9%).

Major structural changes have occurred in the automobile industry since 1978. After a long period of stagnation the indusry began to make large investments--$51 billion (in current $) in the four years 1978 to 1982--reflecting a major shift in emphasis from large to small autos. Much of this investment was spent in restrcturing the production mix from large standard cars to cars that are smaller, have 4-cylinder instead of 8-cylinder engines, and are equipped with front-wheel drive instead of rear-wheel drive transaxles, see Table 2-4.

Among the institutional factors which influence/constrain the industry, four stand out. As shown in Table 2-5, the industry is strongly affected by congressional and government agency rule making, and by numerous government regulations ranging from safety to fuel economy. Historically, industry sales have been affected by oil prices, interest rates, and the business cycle. These same factors, however, also tend to constrain the sale of imports. Two additional factors tend to restrain sales with respect to foreign imports. First, labor relations are characterized by a large labor union influence that has resulted in generous collective bargaining agreements not infrequently exceeding the industry's labor productivity gains. Second, absenteeism has been significantly larger (5.7%) with respect to Japanese experience (less than 1%).

Competitive Issues Affecting the Motor Vehicle Industry

Table 2-6 summarizes export and import statistics and illustrates the fact that the industry is under siege. Imports

TABLE 2-5

DOMINANT CONSTRAINTS AFFECTING THE MOTOR VEHICLE INDUSTRY (SIC 371)

GOVERNMENT REGULATIONS

NUMEROUS DEALINGS WITH SAFETY EXHAUST EMISSIONS, AND FUEL ECONOMY REGULATIONS AFFECT EACH FIRM DIFFERENTLY, AND ALTER RELATIVE COMPETITIVE POSITIONS. FOR EXAMPLE, 237 REGULATORY CHANGES FROM 1960 THROUGH 1975.

FUEL PRICES

SALES AFFECTED BY OIL PRICES, AUTOMOBILES USE 42% OF ALL OIL CONSUMED IN U.S.

LABOR RELATIONS

GENEROUS COLLECTIVE BARGAINING AGREEMENTS WITH LARGE UNION PRESENCE; HIGH ABSENTEEISM (5.7% OF EMPLOYEE HOURS FOR U.S. VERSUS 0.5-1.0% FOR JAPAN).

YEAR	TARGET	STRIKE
1964	CHRYSLER	10 DAYS
1967	FORD	49 DAYS
1970	GMC	67 DAYS
1973	CHRYSLER	9 DAYS
1976	FORD	28 DAYS
1979	GMC	NO STRIKE
1982	NONE	NO STRIKE

FISCAL/MONETARY POLICY

AUTOMOBILE SALES ADVERSELY AFFECTED BY HIGH INTEREST RATES.

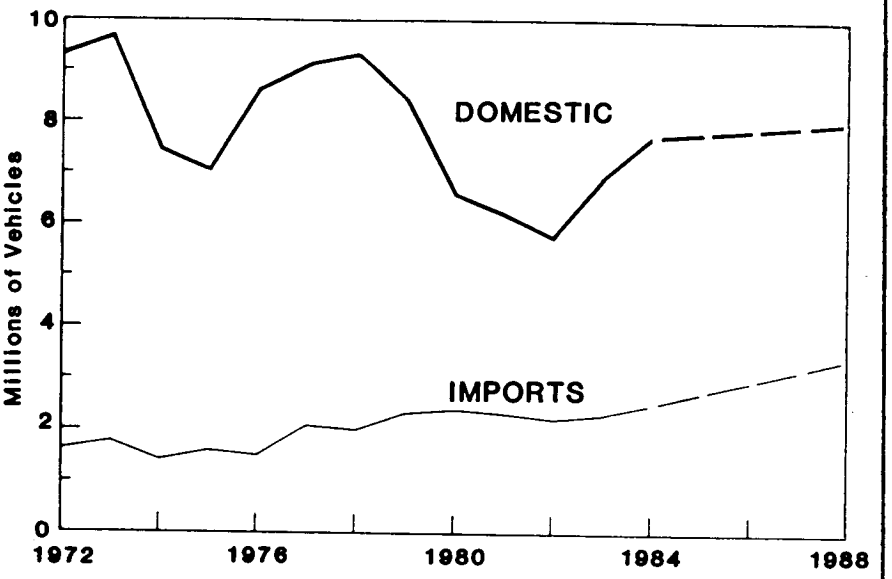
SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

TABLE 2-6

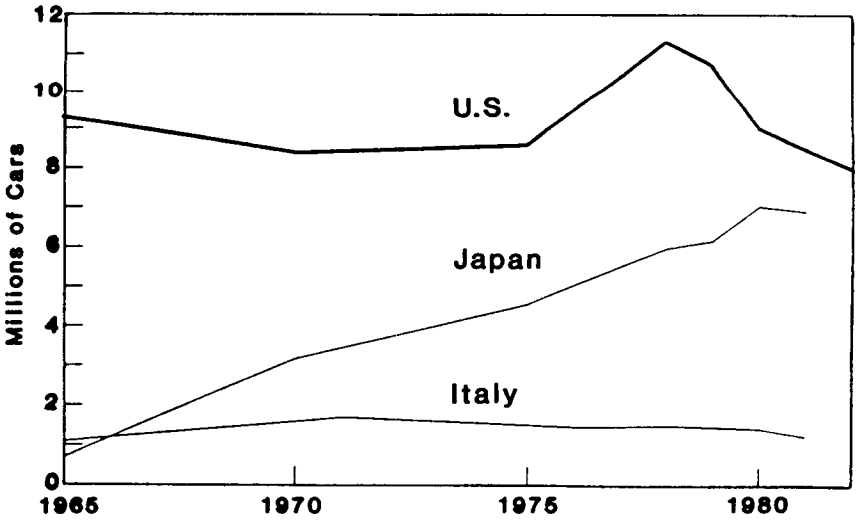
COMPETITIVE POSTURE OF THE MOTOR VEHICLE INDUSTRY (SIC 371)

	1972	1977	1979	1981	1983	ANNUAL GROWTH RATE 1972-83
EXPORTS, BILLION CURRENT $	0.7	2.6	3.2	2.8	1.1	3.7%
IMPORTS, BILLION CURRENT $	3.5	7.6	12.7	15.9	18.4	16.4%

DOMESTIC AND IMPORT SALES



AUTOMOBILE PRODUCTION



SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

currently account for almost 30% of automobile unit sales; when measured in dollars, these imports have increased at an average annual rate of 16.4% during 1972-83, while exports have grown at only 3.7% during the same period. Automobile production in the U.S. has dropped to eight million units in 1982 from 9.6 million in 1965 (after a peak of over eleven million in 1978). Japanese production has risen from 0.7 million to over seven million over the same time period, while Italian production has remained flat at about one million. Without quotas for Japanese manufactures, domestic automobile production may have been even more severely impacted. This shift towards imports on the part of the U.S. public has been superficially attributed to a shift in consumer preferences from large to small cars, induced in part by high fuel costs, and in part by increasing traffic congestion, e.g., parking problems. A deeper evaluation however, shows that U.S. manufacturers could and did produce smaller cars, but that these failed to sell because of three principal factors vis-a-vis the foreign product:

- Lower product quality,
- Lower reliability,
- Higher cost.

Quality indices of domestic versus foreign automobiles are shown in Table 2-7. In 1979, domestic automobiles were ranked inferior to foreign makes in terms of assembly quality or "fit and finish" as well as on ratings of body and mechanical repair frequency. As regards reliability, recalls resulting from safety related defects were considerably higher for domestic than for foreign auto makers until 1979, Figure 2-2. Note, however that if the recall data are normalized to number of automobiles recalled per recall campaign (a recall campaign is the notification by a motor vehicle manufacturer of a safety defect to the Secretary of the U.S. Department of Transportation, owners, purchasers, and dealers), domestic automakers compare favorably with foreign makers. In recent years, 1979, 1981 and 1982, there have

TABLE 2-7

QUALITY INDICES OF MOTOR VEHICLES,
U.S. VERSUS IMPORTS, 1979

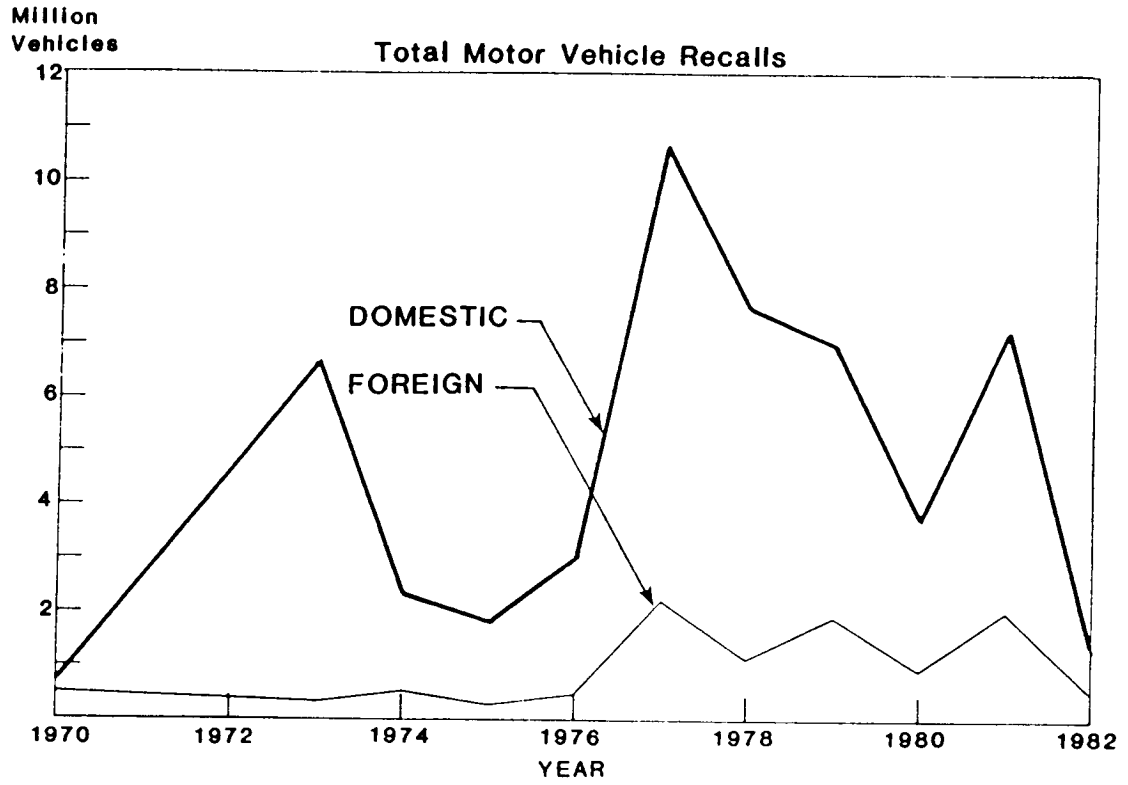
CONDITION OF CAR AT DELIVERY
(SCALE OF 1 - 10; 10 IS EXCELLENT)

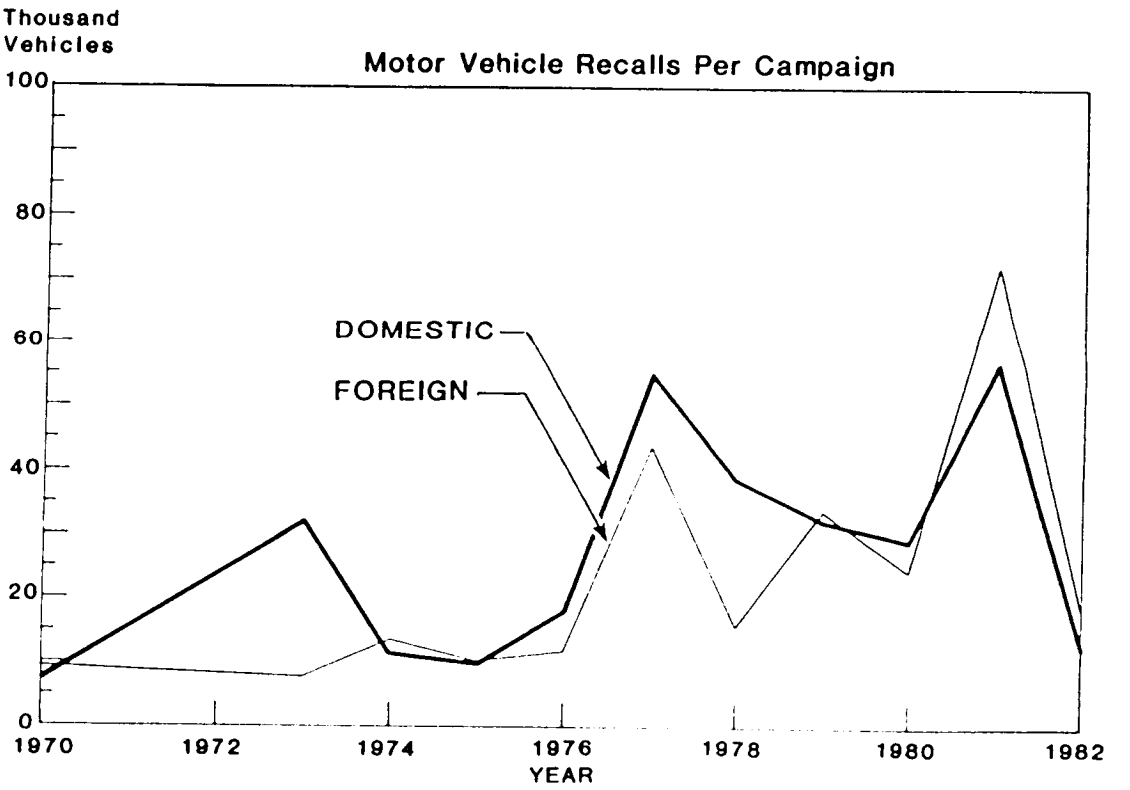
TYPE OF CAR	DOMESTIC	IMPORTS
SUBCOMPACT	6.4	7.9
COMPACT	6.2	7.7
MIDSIZE	6.6	8.1
STANDARD	6.8	—

RATINGS OF BODY AND MECHANICAL REPAIR FREQUENCY, 1979
(20 = BEST; 10 = AVERAGE; 0 = WORST)

MAKE	BODY	MECHANICAL
BUICK	10	10
CHEVROLET	4	8
DODGE	8	8
FORD	9	7
LINCOLN	10	10
OLDSMOBILE	11	9
DATSUN	14	11
HONDA	16	12
MAZDA	18	13
TOYOTA	17	12
VOLKSWAGEN	14	11
VOLVO	16	11

SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL





Source: Calculated From U.S. Dept. Of Commerce,
Bureau Of The Census Data

Figure 2-2. Motor Vehicle Safety Recalls

been more cars recalled per campaign by foreign automobile makers, e.g., 18,000 foreign versus 12,000 domestic in 1982. This would indicate that the quality trend is beginning to reverse.

The cost factor is intimately connected with the industry's productivity, as discussed below.

Productivity in the Motor Vehicle Industry

The data in Table 2-4, drawn from unpublished BLS data, show that labor productivity (output per employee hour) in the auto industry has been steadily growing over the last 15 years, except for temporary slowdowns, the last of which occurred in 1978. Currently, productivity shows a marked upswing. An important question is whether this productivity growth is sufficient to offset lower foreign labor costs. Figure 2-3 and Table 2-8 show the distribution of labor costs in the assembly of the typical automobile, exclusive of the production of input materials and parts. The Table also compares the productivity of typical U.S. and Japanese processes. It shows that total labor required in 1978 to manufacture a motor vehicle was 74 hours in the U.S. compared to only 39 hours in Japan. The largest difference, more than twofold, is in labor hours required for the assembly process. This has been attributed to differences in the sophistication of automation. Note that these labor costs apply only to automobile assemblage. Table 2-4 shows that approximately 75% of the average car's costs is in materials. See Figure 2-1 for detail. Implicit in the costs of these materials are additional labor costs.

Table 2-9 compares the cost and labor aggregates of Ford Motor Co. with those of Mazda Motor Corporation. In 1979 Mazda required 47 labor hours costing $491 to assemble a car; Ford needed 112 labor hours costing $2,464. These figures need to be tempered by the respective size mix of the cars; whereas Ford's

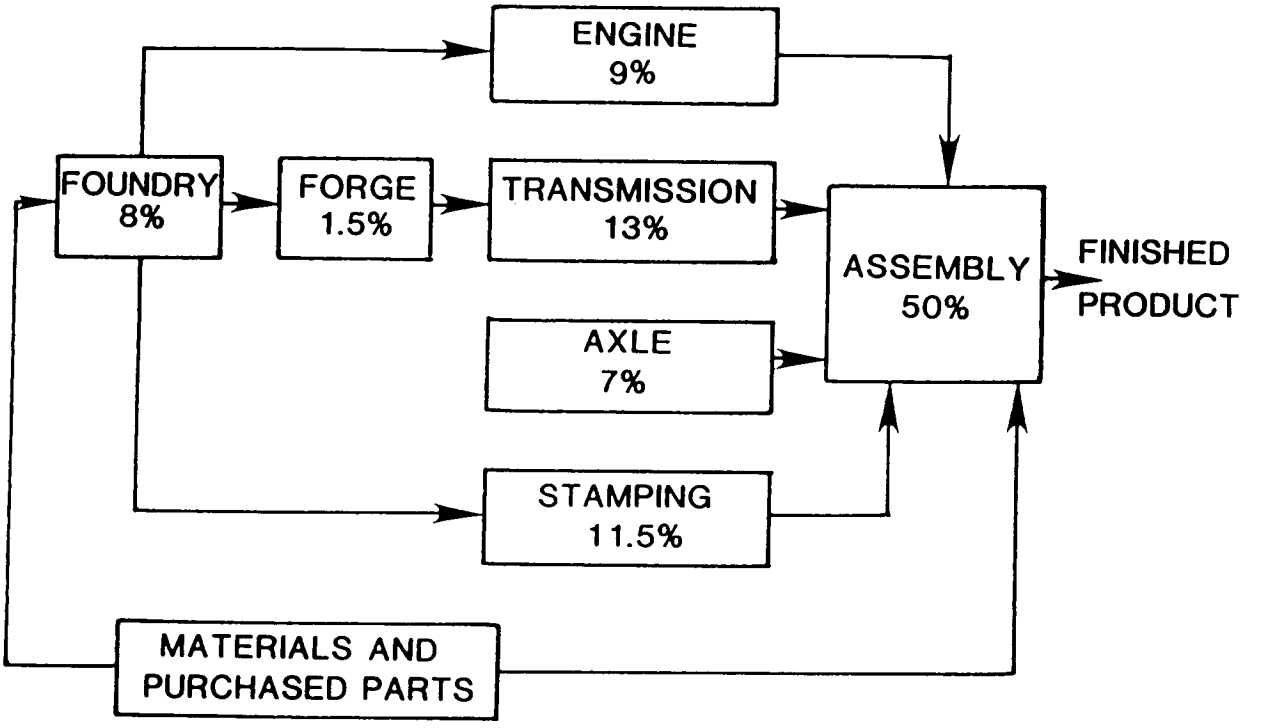


Figure 2-3. Average Manufacturing Labor Cost Distribution of Passenger Automobile Assemblage Process.

TABLE 2-8

LABOR REQUIREMENT FOR MOTOR VEHICLE ASSEMBLAGE: U.S. COMPARED TO JAPAN[a]

LABOR REQUIREMENTS
SELECTED PLANTS IN 1978

PROCESS	LABOR HOURS/VEHICLE U.S.	JAPAN
ASSEMBLY	38	17
STAMPING	10	4
ENGINE	7	4
TRANSMISSION	8	6
AXLE	5	3
FOUNDRY	5	4
FORGE	1	1
TOTAL MANUFACTURE	74	39

[a] EXCLUSIVE OF MATERIALS AND INPUT PARTS

SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

production was largely in "standard" autos, Mazda's was overwhelmingly in compacts and subcompacts. Even when adjusted for this factor however, plus costs of oceanic transportation, the Japanese advantage in landed cost was still of order $1,000 per vehicle. The challenge is particularly severe because the average Japanese cost of labor ($10.50/hour including fringe benefits) was less than half the U.S. cost ($21.90/hour including benefits). On the surface, this means that, in order to remain competitive, U.S. labor productivity should increase by a factor of two to three. Note, however, that the cost advantage from increased labor productivity is small. This is because only 7% of the average car assemblage cost is manufacturing labor, see Table 2-4. Even if labor costs were reduced to zero, the cost savings on a $10,000 car would only be $700.

TABLE 2-9
COMPARATIVE LABOR/COSTS,
FORD AND MAZDA, 1979

	FORD	MAZDA
PRODUCTION CARS AND TRUCKS (MILLIONS)	3.2	1.0
AUTOMOTIVE EMPLOYMENT (THOUSAND)	220	24
EMPLOYEE HOURS, AUTOMOTIVE (MILLIONS)	356	46
AUTOMOTIVE EMPLOYEE COST (MILLION $)	7794	482
EMPLOYEE HOURS/VEHICLE, UNCORRECTED	112	47
EMPLOYEE HOURS/VEHICLE, CORRECTED[a]	87	56
EMPLOYEE COST/VEHICLE, $, UNCORRECTED	2464	491
EMPLOYEE COST/VEHICLE, $, CORRECTED[a]	1893	589

[a] USING PRODUCT MIX/SIZE ADJUSTMENT

SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

Capital productivity for the transportation equipment industry as a whole is shown in Figure 2-4. It can be seen that an investment of approximately one dollar is needed currently to produce a dollar of added value. Capital investment needs are growing: Investment per hour worked, expressed in 1972 dollars, has risen 2.6% per year in two decades from $8.26 in 1960 to $13.48 in 1979. The productivity of capital thus appears to be dwindling, despite the technological innovations of the last twenty years. Corresponding Japanese data are scarce, but all indications are that they are laboring under the same constraints. The major difference lies in the significantly lower costs of capital, see Figure 2-5.

This dwindling "margin of maneuver" of labor and capital portends the onset of an era in which the world's automotive industry will be faced with severe "dog eat dog" competition where the volume of sales will hinge upon small advantages, e.g., a few percentage points in price, somewhat better financing terms, marginal improvements in quality. The situation is typical of highly mature technologies. In this environment, how then can the U.S. auto industry meet the challenge? And to what extent does new technology play a role in the strategy?

Role of Technology in Long-term Strategic Outlook

In the early 1900s, when motor cars were few, France had the largest number of autos per capita. Since then, the U.S. has grown to lead all other nations both in the absolute number of registered motor vehicles and in the number of autos per capita. The U.S. leadership is even more pronounced when considering that most U.S. autos were, until recently, approximately twice to four times the size (by weight and engine capacity) of the average foreign car. However, except for significant improvements in efficiency, reliability and comfort, the basic technology of the automobile is not fundamentally different from eighty years ago.

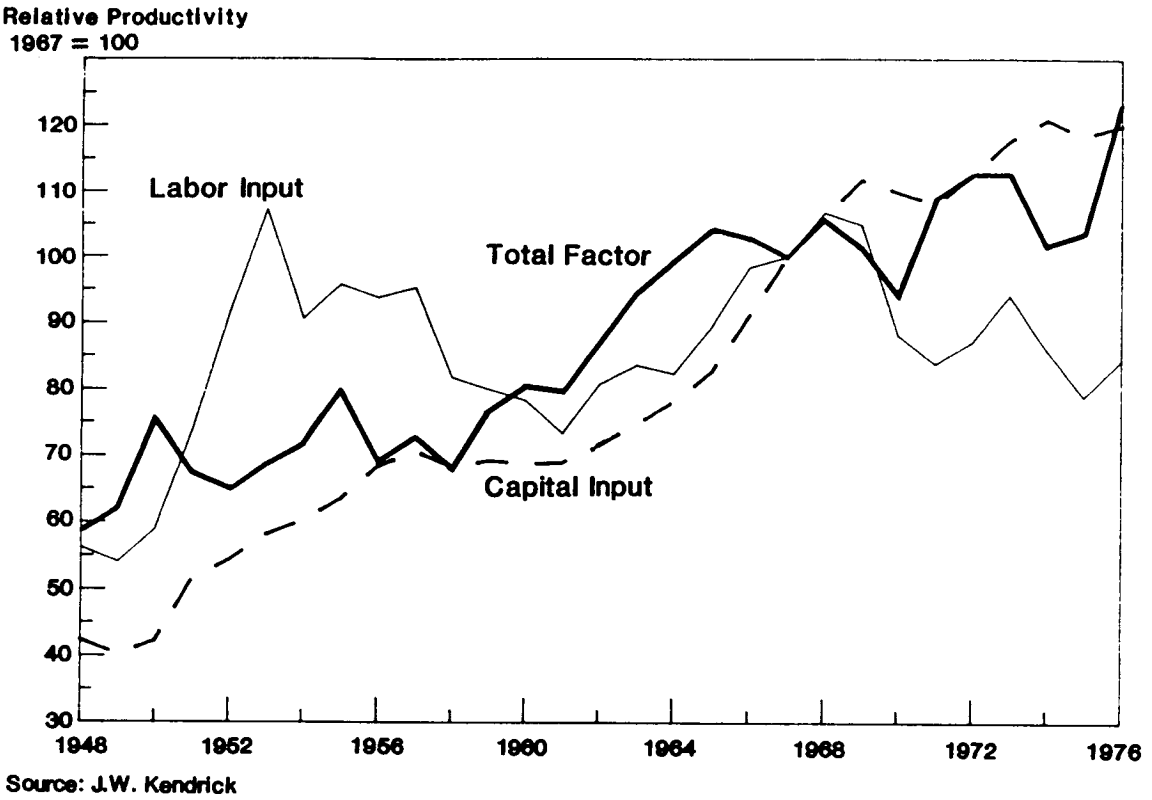


Figure 2-4. Productivity in Transportation Equipment

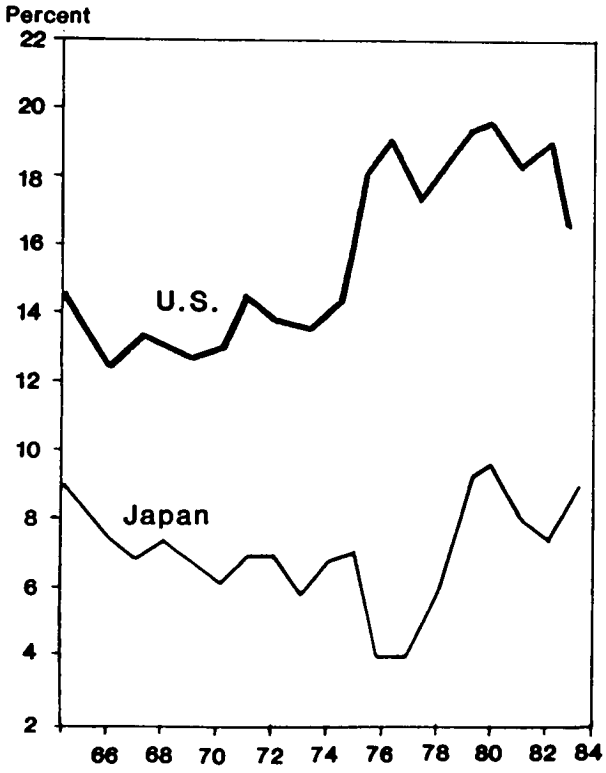


Figure 2-5. Relative Cost of Investment Capital, 1964 - 1983

Source: "High Cost Of Capital", 1983

Intuitively, the number of conventional autos in any given country or market area cannot grow indefinitely, but must be limited by some kind of saturation effect. Studies conducted in several developed countries appear to confirm this fact. Thus, important strategic questions are: How close are we now to saturation of the conventional auto market? And, how much room is left to grow for the conventional technology?

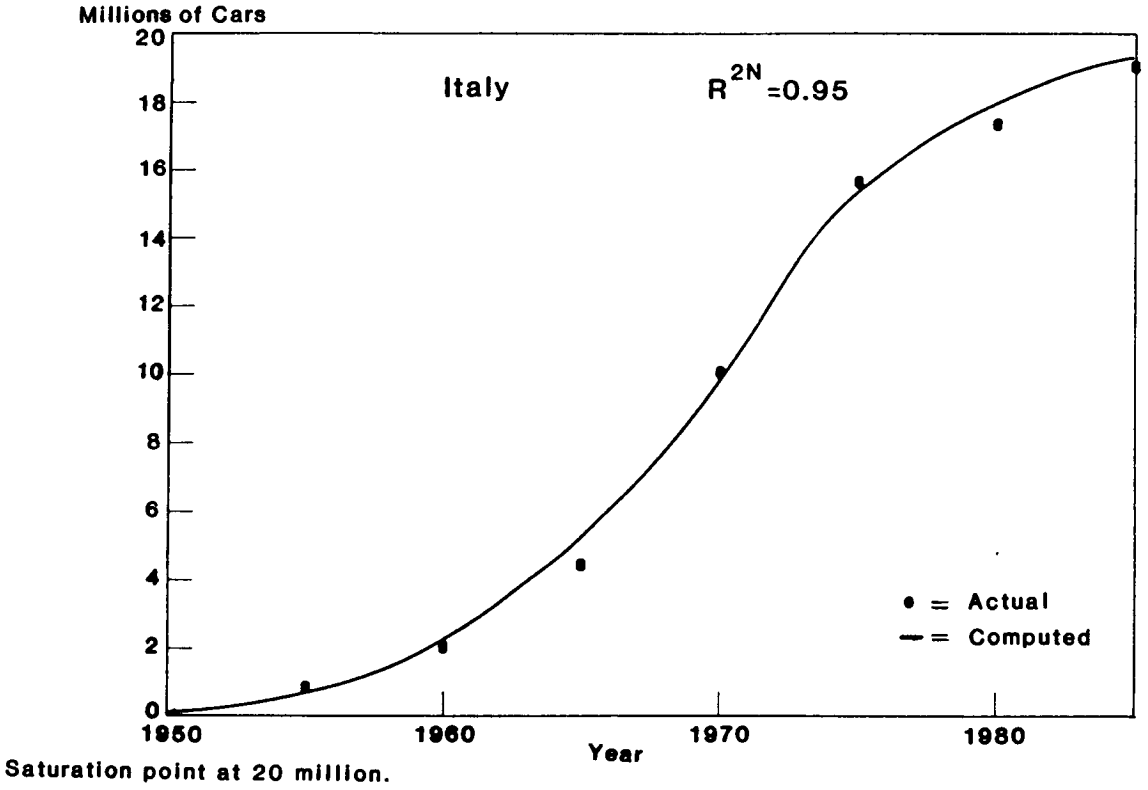
An imaginative approach to the question of saturation has been taken by Cesare Marchetti of the International Institute for Applied Systems Analysis Laxenberg, Austria. He shows that the historical trends of passenger motor vehicle registrations in all developed countries follow a logistic S-curve: A slow initial development is followed by a sustained increase which eventually flattens out. Following Marchetti, if the motor vehicle registration data are fitted to logistic curves of the type:

$$N = \frac{N_{sat} \quad ae^{-bt}}{1 + ae^{-bt}}$$

where:
- N = number of autos in a given country or region at time t
- N_{sat} = saturation number of autos
- t = time in years
- a,b = coefficients peculiar to the country or region

a surprisingly good fit is observed, especially for the years following WWII. As an example, Figure 2-6 shows the fit of computed versus the actual passenger car registrations for the U.S. and Italy.

Figure 2-7 depicts the Marchetti automobile S-curves for the principal developed nations. As Marchetti points out, the exact reasons for the "S curve" behavior are imperfectly known. In particular, the saturation level appears to be weakly affected by population size, but to depend on region-specific factors as yet not fully understood.



Saturation point at 20 million.

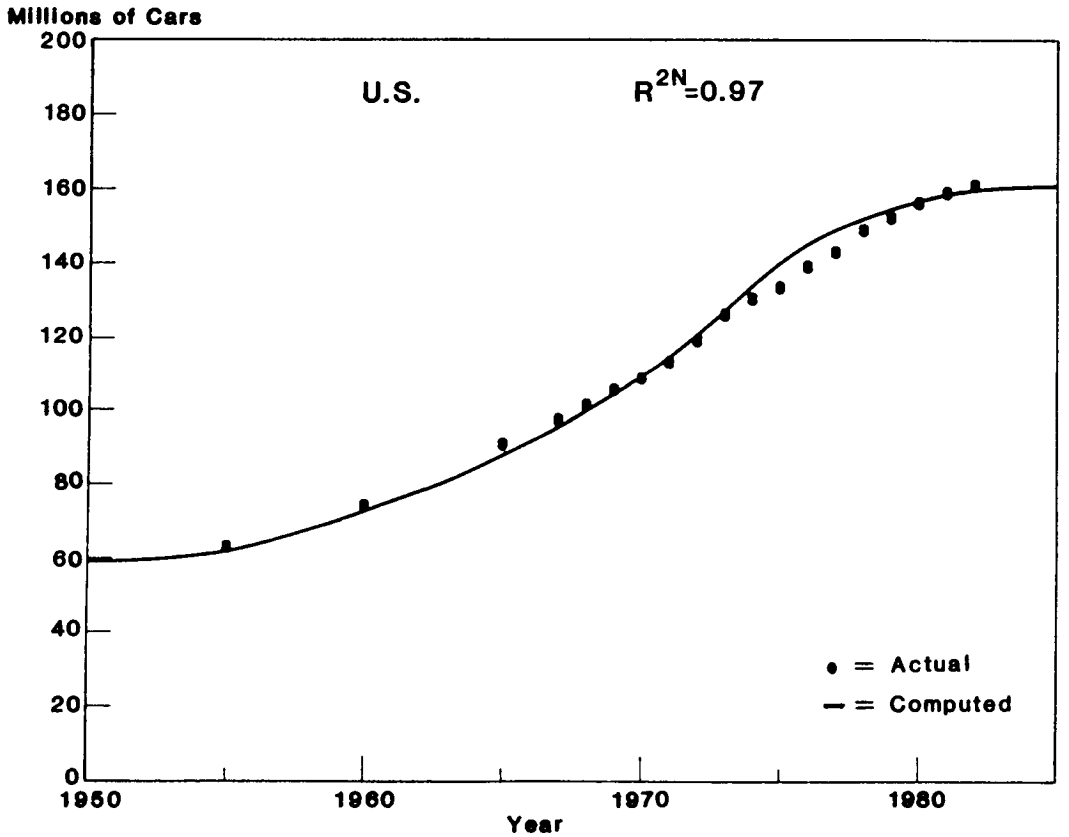


Figure 2-6. Historical Fit Between Car Registrations and Marchetti Logistic Curve

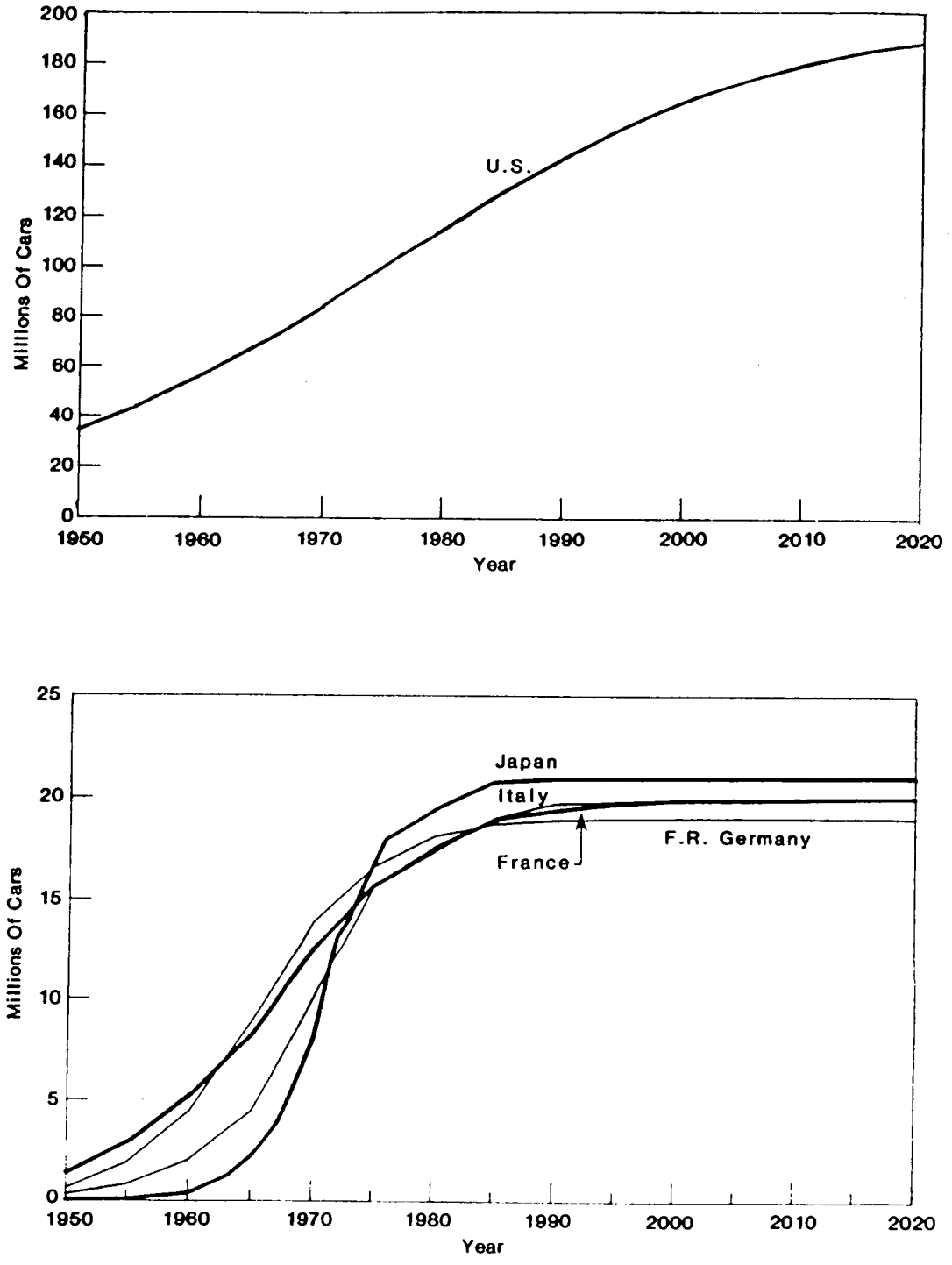


Figure 2-7. Car Registration for the U.S. and Selected Countries Marchetti Logistic Extrapolation

Figure 2-7 shows a trend towards saturation in all developed countries; while the U.S. appears to be saturating later, it is on a path of ever-diminishing incremental growth.

What do these factors portend as regards the industry's strategic outlook? Two major points:

- The automotive demand in the developed economies appears to be heading towards a phase of saturation, in which the total auto market demand will be substantially "flat." In such a market, "new car" sales will predominantly be replacements for worn out or obsolescent vehicles.

- The significant potential expansion that appears to exist in third world markets is hampered by the poverty in these regions. Development of these regions requires investments to exploit local resources to generate the needed moneys. The risks, largely from political instabilities, have thus far severely hampered and curtailed such developments.

The "flat" market scenario indicates that the automotive industry, as presently structured, is neither "sunset" nor "sunrise;" rather, that its pattern of growth is substantially stationary. Significant expansion of the U.S. automotive industry, short of U.S.-foreign industry mergers, can only be achieved by displacing foreign manufacturers, both domestically and abroad. From what has been observed regarding U.S.-Japanese competition, this would entail significant reductions of cost and/or improvements in quality characteristics. In this connection, several points stand out:

- As observed earlier, the small residual margin currently available to labor productivity (approximately 7%) indicates that "labor-saving productivity" is not the smart way to go.

- While automation has been highly touted, it's introduction costs money. The dwindling productivity of capital during the last two decades indicates that this approach, albeit necessary in the near-term to maintain competitiveness, is not the innovative way to go.

- Thus technology, not labor and/or capital productivity, offers the hope to leapfrog the competition.

What technologies, then, are "coming down the pike" and what are the prospects that they can bring about a turn-around of the U.S. automotive industry? These questions are addressed following.

New Technologies in the Motor Vehicle Industry

Table 2-10 summarizes the new technologies currently being developed and planned by the industry. They fall into the following major groupings:

1. More efficient conventional propulsion. These are Internal Combustion Engines (ICE) using conventional hydrocarbon fuels more efficiently, or using nonconventional, domestically available hydrocarbon fuels such as gas, pulverized coal, fuels from renewable resources, e.g., alcohol. These technologies are essentially oriented to reducing operating costs.

2. Improved automotive subsystems, e.g., transmission; bodies with lower aerodynamic friction; internal energy and operations management subsystems, e.g., microprocessors. These technologies are oriented towards improved quality and somewhat reduced operating costs.

3. Improved methods, techniques, technologies of manufacture. These are oriented primarily towards reduction of labor costs.

TABLE 2-10

NEW MOTOR VEHICLE TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT	APPROXIMATE ERA OF SIGNIFICANT
ICE—CONVENTIONAL FUELS			1985 1990 1995 2000
• DIRECT INJECTED STRATIFIED CHARGE	FUEL INJECTION COMBINED WITH EVEN DISPERSION OF CHARGE	INCREASED FUEL EFFICIENCY	
• ADVANCED DIESEL (ADIABATIC TURBO COMPOUND)	COMBINATION OF DIESEL, TURBO-CHARGING AND TURBINES	INCREASED FUEL EFFICIENCY	
ICE—SPECIAL OR MULTIFUEL			
• TURBINE	AUTOMOTIVE ADAPTATION OF TURBINE TECHNOLOGY	INCREASED FUEL EFFICIENCY	
• STIRLING	AUTOMOTIVE USE OF MORE EFFICIENT STIRLING CYCLE ENGINE	INCREASED FUEL EFFICIENCY	
• METHANOL, GAS, COAL	NEW FUEL CAN BE USED IN CONVENTIONAL ENGINES	USE OF MORE ECONOMIC/AVAILABLE FUELS	
PRODUCTION TECHNIQUES			
• MODULAR CONSTRUCTION	USE OF "INTELLIGENT ROBOTS" IN MFG.	LOWER COST	
MECHANICAL AND MANAGEMENT SYSTEMS			
• CONTINUOUSLY VARIABLE TRANSMISSION	PULLEYS LINKED TO STEEL BELT—NO GEARS	INCREASED FUEL EFFICIENCY	
• NEW MATERIALS	STRUCTURAL PLASTICS, CERAMICS	DECREASED ENERGY DEMAND, LOWER COST	
• ELECTRONICS/COMPUTERS	OPTIMAL MANAGEMENTS OF CAR FUNCTIONS	INCREASED FUEL EFFICIENCY, CONVENIENCE	
• HIGH PRESSURE TIRES	REDUCED ROLLING RESISTANCE	DECREASED FUEL DEMAND	
• DESIGN METHODS/MATERIALS FOR CRASHWORTHINESS	MORE CRASHWORTHY AUTOMOBILE	INCREASED SAFETY	
NEW PROPULSION METHODS			
• ELECTRIC	ELECTRIC BATTERY STORAGE AND ENGINE	ELIMINATES OIL FUEL	
• INERTIAL	FLY WHEEL ENERGY STORAGE	ELIMINATES OIL FUEL	
• FUEL CELL—ELECTRIC	CATALYTIC CONVERSION OF HYDROCARBON FUELS	MUCH INCREASED FUEL EFFICIENCY	
• HYBRID	COMBINATION OF NEW PROPULSION AND ICE	INCREASED FUEL EFFICIENCY	

4. Novel types of propulsion. Principal among these:

   a. Conversion of the chemical energy of fuels into electrical energy at much higher efficiencies than available through ICE. The most representative device is the fuel cell.

   b. Energy storage devices capable of utilizing economical types of stationary energy to efficiently deliver mobile energy. Representative devices are inertia wheels, and electrical storage batteries.

Technology groups 1, 2, and 3 are essentially "more of the same" improvements to conventional technologies. The problem is that they are well-known to foreign competitors, who are also striving towards their development. Their introduction would not avoid an era of "dog eat dog" competition centering around a few percent price discounts and marginal (even if highly advertised) quality advantages, that would soon be caught up with by competition. In contrast, the group 4 technologies offer the possibility of dramatic breakthrough such as the development of the socalled "world car." Much discussed, notably in Japanese publications, salient characteristics of the world car would be low purchase cost, low operating cost, high reliability, and freedom from energy "surprises." Should U.S. industry be the first to develop this product, it would enjoy the immense advantage of the largest domestic market in the world. This would allow it to reach competitive status before other nations with more restricted domestic markets, see Figure 2-7. What new technological thrust could lead to the world car? Foremost is the development of practical mobile energy sources. The status and outlook for these is summarized of following.

Mobile Energy Storage Technologies

Because of their high energy-to-weight-ratio, conventional hydrocarbon fuels are the prime sources of mobile energy. One

kilogram of gasoline or diesel fuel contains approximately 12kWh of energy. Even at the low thermal efficiencies currently available from variable-speed, automotive Internal Combustion Engines (ICE), (average of order 20% over the speed range of 0-60 mph) this is still better than 2kWh/kg. Alternative energy sources which are most plentifully available to the U.S. (coal, nuclear) are not well-suited to mobile use, but to producing stationary energy. A similar restriction will apply to fusion energy, whenever it becomes available.

The U.S. electric utility industry currently produces 2.5 trillion kWh of stationary energy per year. The utilization factor is about 0.45. Utilization factor is the ratio of energy actually produced to the energy that could be generated by the existing plant. The utilization factor is low because the generating plant is sized to accommodate the peak energy demand, which lasts only for a fraction of the time. The demand drops at night, during weekends and other low demand periods. Thus a "latent" energy of approximately three trillion kWh/year is potentially available in the U.S. without significant modification to the existing plant. This is equivalent to the energy required to propel 160 million autos over approximately 300km (180 miles), every day, at 70km/h (40mph). Key to tapping this potential is the development of low-cost, low-weight storage devices.

Figure 2-8 shows typical power and energy requirements for a compact auto. Note that the energy consumed in overcoming grades can, in an electric vehicle, be largely recovered via dynamic braking.

Based on typical system efficiencies (of the order of 50 to 70%), the Figure shows that a 1,000kg (2,200lbs) auto, traveling at 100km/h (60mph), over a modern highway requires on the order of 12 to 15 kilowatts of output power from the storage device. A sustained 5-hour drive, covering 450km (280 miles) would thus require energy storage of the order of 60 to 75kWh.

To achieve a reasonable mass ratio of storage device to vehicle weight (about 10%) the energy storage density required is of order 1kWh/kg. This compares with 2kWh/kg for gasoline or diesel fuel, 0.05 to 0.1kWh/kg for conventional mobile storage batteries, 0.2kWh/kg for very advanced storage batteries.

Thus, the ability to realize the latent energy potential of stationary plants rests on development of energy storage only one order of magnitude beyond current technology.

Volume V, Section E.2, discusses the long-term research issues involved with development of improved storage devices and assesses the likelihood of realizing a "leapfrog" advance--with potential for dramatically changing the prospects of the auto industry.

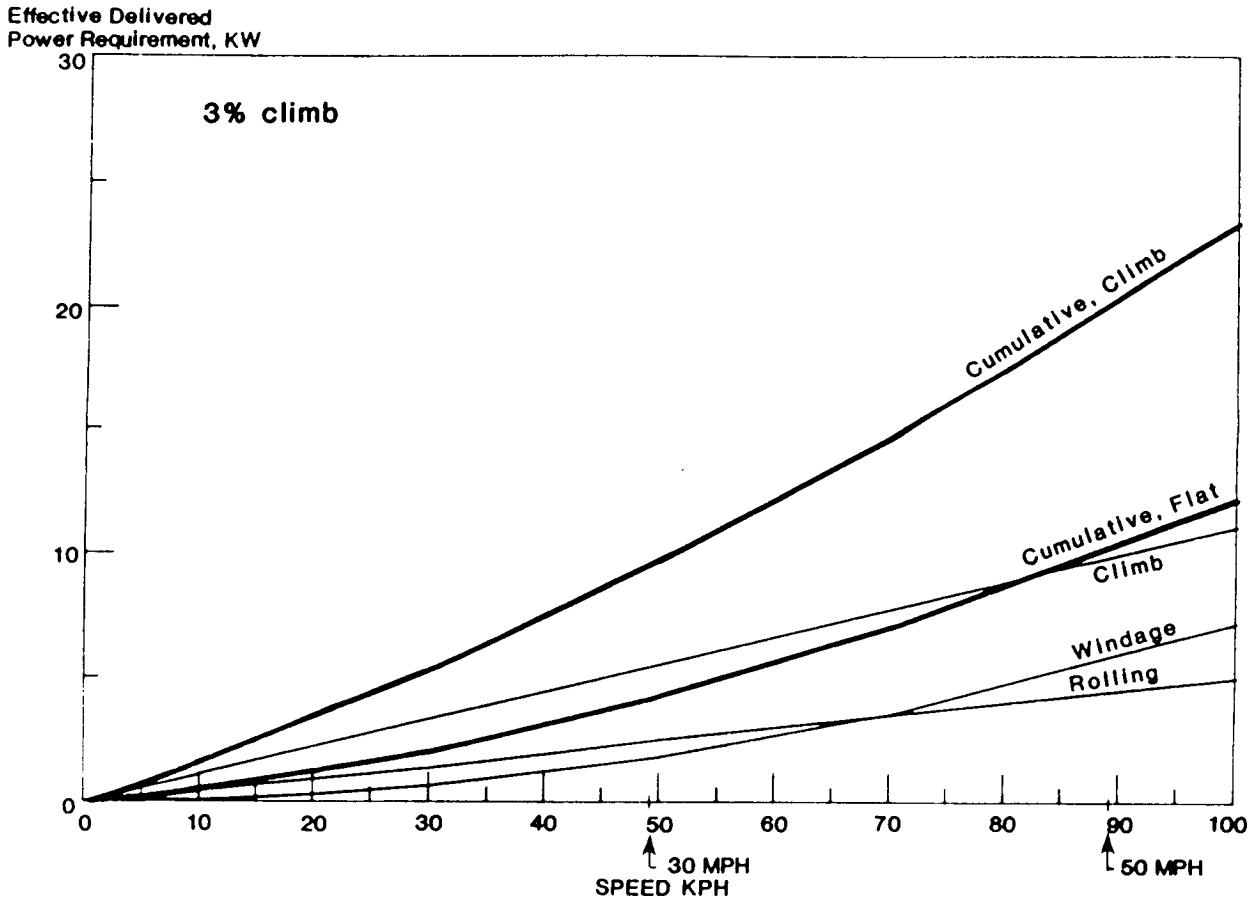


Figure 2-8. Output Power Requirements for a Typical Compact Autos, 1000 Kg Loaded Weight

B.2.2 THE AEROSPACE INDUSTRY (SICs 372 AND 376)

The aerospace industry includes those subdivisions that manufacture, research and develop complete military and civil aircraft and helicopters; engines for aircraft and helicopters; and missiles, space vehicles and their parts. Table 2-11 indicates these major products by Standard Industrial Classification.

This industry is second only to agriculture in contribution to balance of payments ($15.4 billion in 1980) and represents the largest high technology product exporter in the U.S.

The aerospace subdivisions accounted for 46% of the shipments of the transportation equipment subsector in 1980. By 1982, this was reduced to 33%. This decline was occasioned by a sharp reduction of civil aircraft and helicopter shipments associated with the worldwide recession of 1982-1983 and increased foreign competition in commercial transport manufacturing, e.g., Airbus Industries and several foreign general aviation aircraft manufacturers. Shipments accelerated in military aircraft and missiles during this same period, but were not sufficient to offset civil aircraft and helicopter declines.

The business and structural profiles of the aerospace subdivisions are summarized in Tables 2-12 and 2-13, respectively. The bulk of the indicators portray an internationally competitive, high technology industry with large R&D and capital investment requirements.

The production and sales of the aerospace industry can be conveniently divided into four categories:

- Civil Aircraft (including helicopters),
- Military Aircraft (including helicopters),

TABLE 2-11

CLASSIFICATION OF MAJOR PRODUCTS OF THE AEROSPACE INDUSTRY AND CONTRIBUTION TO AEROSPACE SHIPMENTS IN 1980

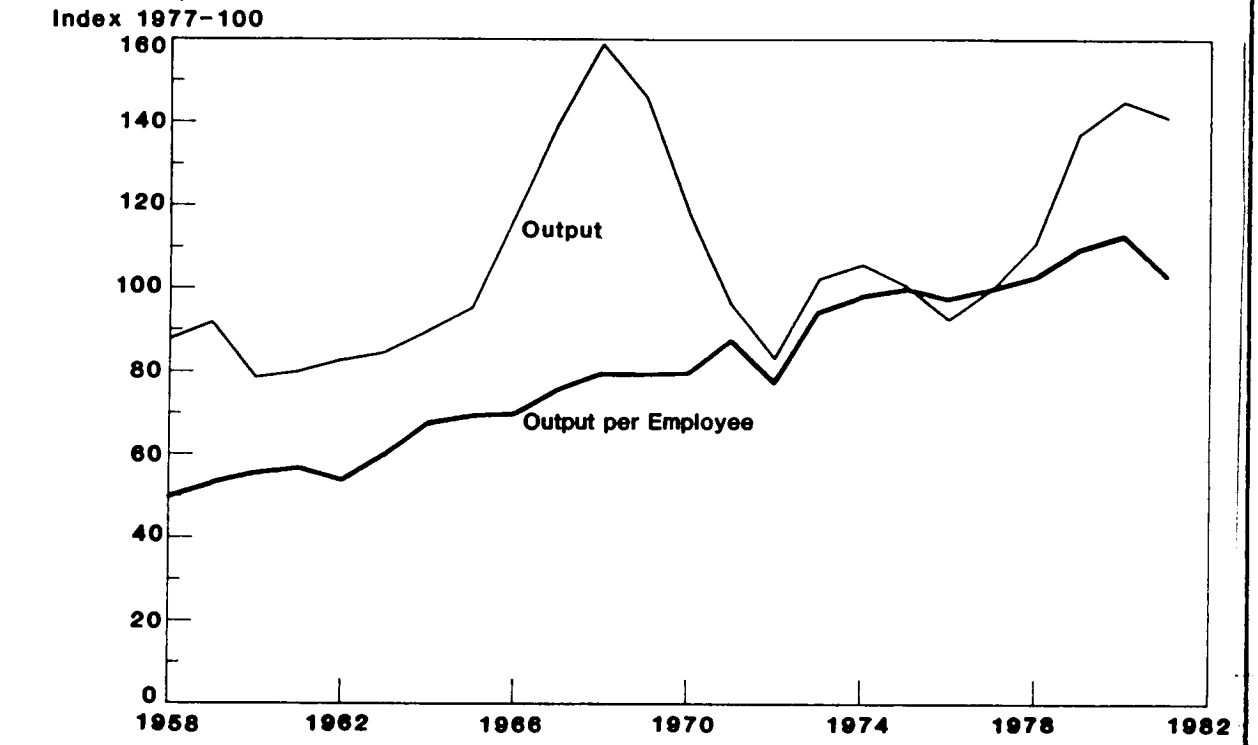
SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
372	**AIRCRAFT AND PARTS**	
	AIRCRAFT (INCL. HELICOPTERS)	79.0
	AIRCRAFT ENGINES & PARTS	
	AUXILIARY EQUIPMENT	
	ASSOCIATED RESEARCH AND DEVELOPMENT	
376	**GUIDED MISSILES AND SPACE VEHICLES AND PARTS**	
	GUIDED MISSILES	21.0
	SPACE VEHICLES	
	SPACE PROPULSION UNITS	
	AUXILIARY EQUIPMENT	
	ASSOCIATED RESEARCH AND DEVELOPMENT	

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1984
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972

TABLE 2-12

BUSINESS PROFILE OF THE AEROSPACE INDUSTRY

	1972	1977	1979	1981	1982	EST. 1983	EST. 1984
SHIPMENTS (BILLION $)							
CURRENT $	21.1	32.4	48.3	64.8	63.4	73.1	79.4
1972 $	21.1	21.0	26.0	27.5	24.9	26.8	27.2
TOTAL EMPLOYMENT (THOUSANDS)	598.8	550.6	682.1	733.6	707.2	689.7	682.0



Source: Unpublished BLS Data

R&D EMPLOYMENT, 1982 — 95,000 (19% OF ALL INDUSTRY)

VALUE OF PLANT, 1982, CURRENT BILLION $ — $12.7

NEW CAPITAL EXPENDITURES	1976	1982
CURRENT BILLION $	2.0	6.0

BACKLOG (1983)

MONTHS	16
VALUE, BILLION $	95.6

SOURCES: AEROSPACE INDUSTRIES ASSOCIATION
U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK

TABLE 2-13

STRUCTURAL PROFILE OF THE AEROSPACE INDUSTRY

ESTABLISHMENTS (1977) (CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	647
INTERMEDIATE (20-100)	542
LARGE (>1000)	91
TOTAL	1280
(1,133 COMPANIES)	

LEADING FIRMS (1983)

NAME	DOMESTICALLY GENERATED AIR & SPACECRAFT SALES (BILLION $)
BOEING COMPANY	10.66
McDONNELL DOUGLAS	8.11
LOCKHEED	6.49
UNITED TECHNOLOGIES	5.98
MARTIN MARIETTA	3.90
ROCKWELL INT'L	3.69
GENERAL DYNAMICS	3.54
NORTHROP	3.26
TRW	2.60
GRUMMAN	2.22
RAYTHEON CO.	1.19
FAIRCHILD	0.89
TOTAL	52.53

NO. OF ESTABLISHMENTS (>2500 EMPLOYEES)

AIRCRAFT & HELICOPTERS	20
AIRCRAFT EQUIPMENT	8
SPACE PROPULSION	2
AIRCRAFT ENGINES & PARTS	10
GUIDED MISSILES & SPACE VEHICLES	12
SPACE VEHICLE EQUIPMENT	1
TOTAL	53

	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	13%	18%	40%	1%	28%

PREVALENT MODE OF PROCESSING: BATCH, SMALL QUALITY, LABOR INTENSIVE

R&D EXPENDITURES, 1983 ($ BILLION)

INTERNAL	2.4
FEDERAL	9.4

SOURCES: AEROSPACE INDUSTRIES ASSOCIATION
VALUE-LINE INVESTMENT SURVEY, 1984
STANDARD AND POORS CORPORATION, 1984
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977

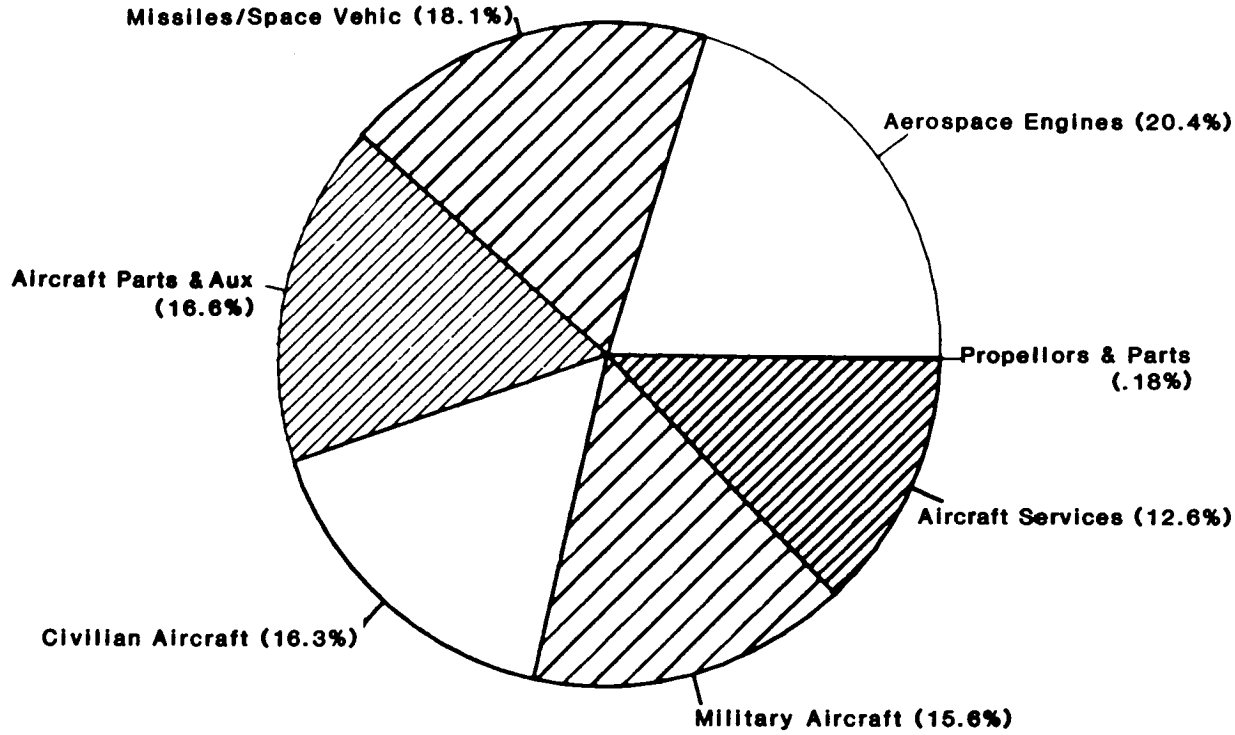
- Missiles,

- Nonaerospace Products.

Product shipment distribution for 1983 is pictured in Figure 2-9.

The business profile (Table 2-12) shows total sales in 1982 of $63.0 billion (1982 $) essentially unchanged from 1981 sales in constant dollars. The 1982 dollar value of sales in all product groups in current dollar terms increased, but civil aircraft production and nonaerospace sales declined. Profits measured as a percent of equity, assets, and sales continued to decline for the 1979 peak through 1982. The total backlog for aerospace increased in 1982 by $6.5 billion, an increase in real terms of $3.14 billion (constant 1972 $). An almost even split in backlog between U.S. government and other aircraft customers continued in 1982, with aircraft, engines and parts continuing their dominant (60%) traditional fraction of this backlog.

Table 2-13 portrays some of the key structural highlights of the U.S. aerospace industry. Slightly over half of all production establishments employ 20 people or less. The ten largest companies accounted for nearly 70% of product shipments in 1983. The production cost breakdown shows that materials costs amounted to 40% of production costs, labor costs amounted to 31%, while capital costs were 28%. The most highly fragmented subdivision of the aerospace industry is the aircraft equipment manufacturers (SIC 3728). The majority (430 of 647, or 66%) of small manufacturing establishments employing less than 20 employees are aircraft equipment manufacturers. Typical products produced by SIC 3728 manufacturers are elevator, airleron, and empennage assemblies, actuators, propellors, brake assemblies, hydraulics, fuel tanks, landing gear, ejector seats, de-icing equipment, etc.



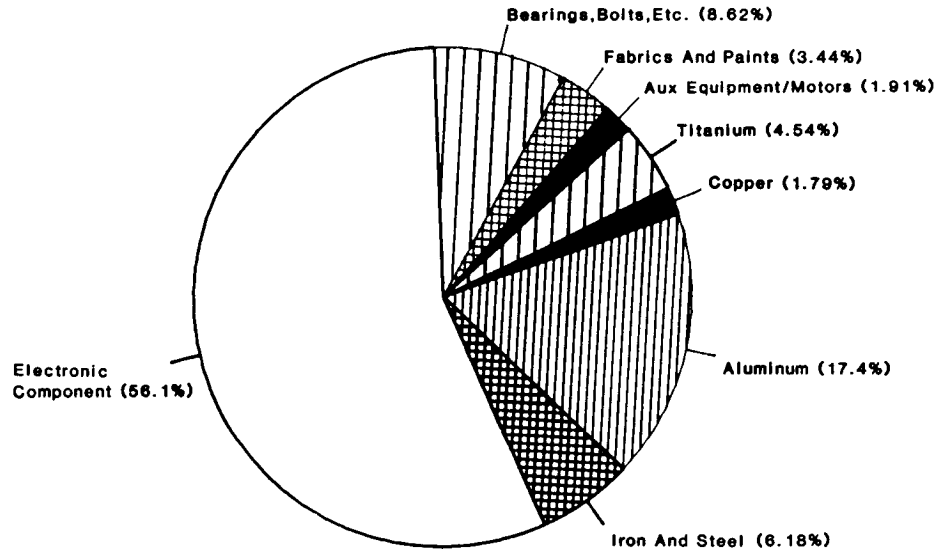
Source: U.S. Department Of Industrial Economics
1984 U.S. Industrial Outlook

Figure 2-9. Breakdown Of Aerospace Vehicles And Equipment Products Shipments (1983)

This subsection will focus primarily on the aircraft manufacturing subdivision (SIC 372), since space systems are beyond the scope of this analysis.

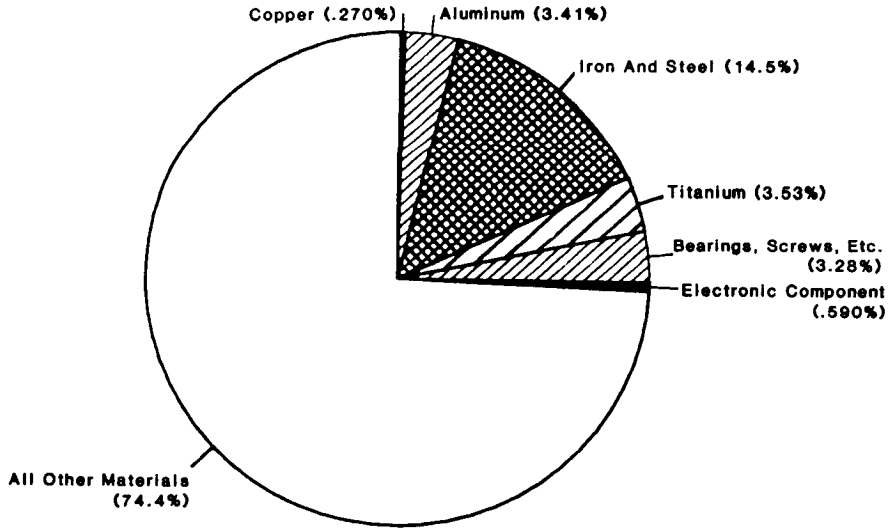
Figures 2-10 and 2-11 illustrate the proportion of production costs allocated for various materials and components of aircraft structures and engines. Electronic components are the most expensive aircraft materials, although these hardware prices should decrease as new technologies employing microprocessor signal conditioning circuits (analog to digital, digital to analog) eliminate more costly instrumentation systems. Electronic equipment prices will continue to dominate materials costs as advances are made toward the all-electric airplane employing electromechanical actuators, digitized voice communications, flat-panel CRT (cathode ray tube) displays, active control technology, and digitized instruments and controls. The next highest portion of structural materials costs is spent on aluminum and its alloys. Aluminum constitutes 80% of the distributed airframe weight of a Boeing 767. Although aluminum prices have remained fairly stable in recent years, prices may increase gradually as a result of increasing energy prices and the increased use of aluminum in automobiles. Copper and steel are also important to the aircraft industry, especially in engines. Of all titanium mill products, 65% are used by the aircraft industry, especially in engines where its high strength at high temperatures is an essential characteristic.

Aircraft manufacturing labor is generally highly skilled. A large proportion (27%) of aircraft engineers work exclusively in R&D programs. Average aerospace industry employment for 1982 (1.16 million) declined slightly from 1981 (1.20 million), continuing at essentially the same level since 1978 and approximately 250,000 above the 1976 low for all aerospace employment. Average week hours (40.2-42.5 hours/week) and average weekly overtime (2.7-4.7 hours/week) have remained within relatively narrow ranges for 1972-1982. Both accession and separation rates



Source: U.S. Department Of Commerce, Bureau Of Census, 1977 Census Of Manufacturers

Figure 2-10. Breakup of Materials Used in Aircraft Airframe Manufacture - Based on Delivered Costs in 1977



Source: U.S. Department Of Commerce, Bureau Of Census, 1977 Census Of Manufacturers

Figure 2-11. Breakup of Materials Used in Aircraft Engine Manufacture (Based on Delivered Costs in 1977)

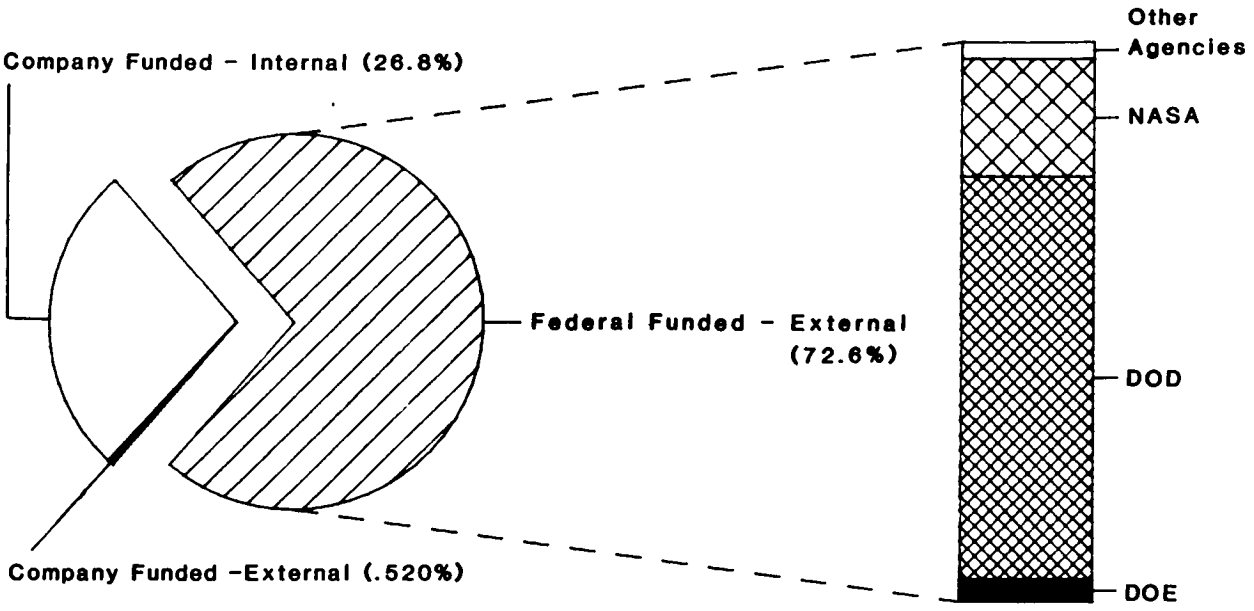
for the industry from 1967-1981[a] show a continuing decline per employee per year indicating increasing employment stability (see Table 2-12). Scientists and engineers in research and development in the aerospace industry (95,000) represented approximately 19% of all R&D scientists and engineers in all U.S. industry in 1982. Figure 2-12 portrays the distribution of internal and external R&D spending.

Capital costs make up 28% of production costs. Aircraft production plants are fairly new; the ten largest companies' average plant age is six years. Still, a large amount of capital is spent on newer, precise machinery. The trend in the aircraft manufacturing industry is toward coupled CAD/CAM and flexible manufacturing systems, which allow engineers to make changes on a part's specifications on-line without having to shutdown the assembly line to retool. Capital costs should continue to remain high as the aircraft manufacturing industry begins to rely increasingly on composites and other new materials technologies, such as metal-matrix based parts and powdered metal manufacturing.

Civil Aircraft Production

A three year decline in civil aircraft shipments continued in 1982 with delivery of 232 commercial transports as compared to 387 in 1981. Of particular note is the decline in orders (backlog) from foreign customers, reduced to 45% in 1982 from a previous high of 50%. Resurgence in this area is dependent on world-wide economic conditions and the fraction of this market captured by Airbus Industries or other later competitors which may enter the market. Civil helicopter shipments declined to 587 in 1982, a drop of 500 units from 1981. A similar reduction of general aviation aircraft shipments, from 9,457 in 1981 to 4,266

[a] BLS data series terminated 1981



Distribution of Federal Aerospace R&D Funds

Source: R&D in Industry in 1981
NSF Survey of Science Resources Series

Figure 2-12. Distribution of R&D Spending for the Aerospace Industry (SICs 372 and 376) in 1981

in 1982, occurred. Military aircraft sales increased again in 1982 in all categories; including 1,154 total aircraft sales and 685 foreign military and commercial sales.

Missile Programs

Missile production, including R&D increased by 20% in 1982. Total backlog declined from $6.5 billion in 1981 to $6.1 billion in 1982.

Space Programs

Combined civil and military space system sales were up 16% to $11 billion in 1982, with the FY 1982 Department of Defense authorization for space programs ($6.4 billion) exceeding NASA ($5.5 billion) for the first time since 1960.

Nonaerospace

Nonaerospace products and services reached $11.5 billion in 1982, continuing a ten year increase. Little increase occurred, however, when measured in constant dollars. These nonaerospace products and services are mentioned here because they are manufactured by establishments primarily engaged in the manufacture of SIC 37 products. These products and services consist primarily of electronic communications and instruments, which are categorized under SIC 36 and SIC 38, respectively.

The dominant factors which constrain the aerospace industry are shown in Table 2-14. The industry is highly dependent on federal military expenditures: 65% of the industry's sales are to the federal government in the form of military aircraft, missiles, and space vehicles; the profit margin on these federal sales is limited by government procurement regulations. The aerospace industry has large capital needs and is constrained both by the availability of capital (currently considered to be

TABLE 2-14

CONSTRAINT PROFILE
OF THE AEROSPACE INDUSTRY

GOVERNMENT INTERACTION	INDUSTRY HIGHLY DEPENDENT ON FEDERAL FUNDING FOR MANUFACTURING ($16.8 BIL. ($16.8 BIL. DOD OUTLAYS VS. $8.6 BIL. COMMERCIAL SALES 1982).
GOVERNMENT REGULATION	PROFIT MARGIN LIMITED BY GOVERNMENT PROCUREMENT REGULATION; MILITARY AIRCRAFT, MISSILES, AND SPACE VEHICLE SALES WERE $43.7 BILLION IN 1982 WHICH WAS 65% OF TOTAL AEROSPACE SALES.
OWNERSHIP STRUCTURE	SMALL NUMBER OF LARGE, PUBLICLY HELD FIRMS (APPROX. 15) WITH MANY SMALLER FIRMS.
QUALITY OF MANAGEMENT	INNOVATIVE MANAGEMENTS TEND TO LEAD OTHER INDUSTRIES.
QUALITY OF ENGINEERING	HIGHER THAN AVERAGE FOR ALL INDUSTRIES (APPROX. ONE-FOURTH OF PERSONNEL ENGAGED IN R&D).
AVAILABILITY OF ENGINEERING	SHORTAGE OF SKILLS EXISTS.
AVAILABILITY OF INVESTMENT CAPITAL	CAPITAL GENERALLY AVAILABLE--MAGNITUDE OF NEW CIVIL PROGRAMS MAY EXCEED FINANCIAL CAPABILITY OF SINGLE COMPANY; $2.0 BILLION REQUIRED OVER 4-YEAR PERIOD TO DELIVER MEDIUM-SIZE COMMERCIAL AIRCRAFT, AN ADDITIONAL $1.0 BILLION REQUIRED FOR 2 YEARS FOLLOWING INITIAL DELIVERY FOR INITIAL HIGH PRODUCTION COSTS.
MARKET DEMAND PATTERN	HIGHLY CYCLICAL.

SOURCES: AEROSPACE INDUSTRIES ASSOCIATION
U.S. DOC/ITS: COMPETITIVE ASSESSMENT OF U.S. CIVIL AIRCRAFT INDUSTRY

adequate) and cost of capital. It is estimated that $3 billion and over 8 years of sales are required before a company can achieve full profitability after the introduction of a new medium-sized civil aircraft. The industry also requires a large number of trained engineering professionals--who continue to remain in short supply. Market demands are highly cyclical, since they are based on economic strength and current DOD expenditures.

Competitive Issues Affecting the Aerospace Industry

Although aerospace companies recorded a strong export performance of $15.6 billion in 1982, this was down from the record 1981 performance of $17.6 billion. The 1982 performance included $9.6 billion in civil exports (down $3.7 billion) and an all time record high of $6 billion in military aircraft exports. Space vehicles and missile exports also increased by $1.5 billion and $1.4 billion, respectively. Thus, the U.S. aerospace industry recorded a positive trade balance of $11.2 billion from 1968 to 1982.

The civil aircraft industry continues to be plagued by rising imports. In 1982, civil aircrafts constituted 92% of all aircraft imports (totaling $1.2 billion). Table 2-15 shows the countries that exported new civil aircraft to the U.S. and the amount of sales. A decline of $2.0 billion in the 1982 aerospace trade balance is entirely a result of a decline in civil aircraft exports.

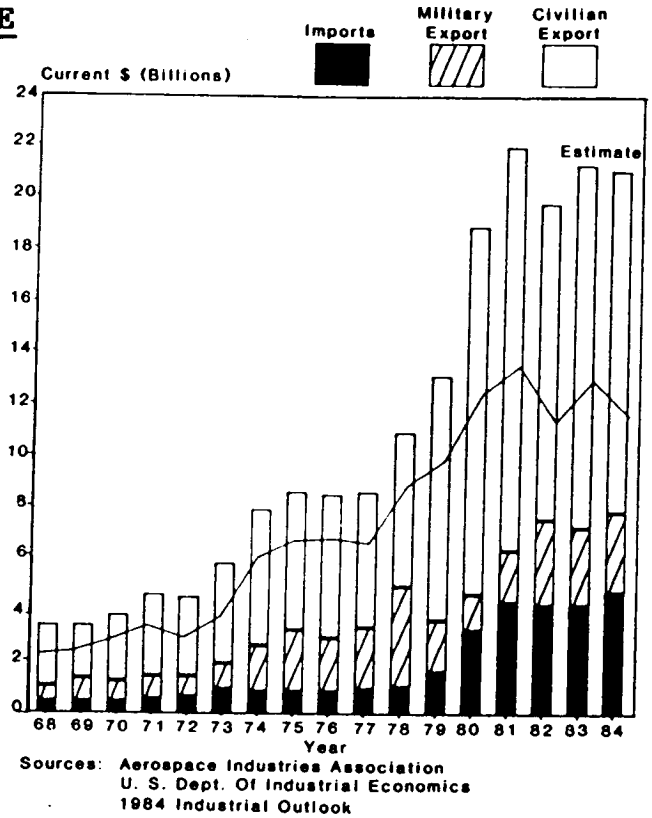
Productivity in the Aerospace Industry

The figure in Table 2-12, drawn from unpublished BLS data, indicates that productivity (output per employee hour) in the aerospace industry rose steadily at a rate of approximately 3% per year through 1980, with the exception of a slight downturn in 1972. According to the Society of Manufacturing Engineers, the

TABLE 2-15

COMPETITIVE POSTURE OF THE AEROSPACE INDUSTRY

EXPORTS, IMPORTS & TRADE BALANCE



Sources: Aerospace Industries Association
U. S. Dept. Of Industrial Economics
1984 Industrial Outlook

NEW CIVIL AIRCRAFT TRADE, BALANCE, 1982

IMPORTS, 1982

IMPORTS		EXPORTS	
COUNTRY	SALES TO U.S. $ MILLION	CONTINENT	SALES $ MILLION
CANADA	307	ASIA	1,172
FRANCE	223	EUROPE	1,158
UNITED KINGDOM	144	MIDDLE EAST	730
ISRAEL	73	LATIN AMERICA & CARIBBEAN	517
BRAZIL	40	AFRICA	361
JAPAN	38	CANADA & GREENLAND	328
MISCELLANEOUS	100	OCEANIA	290
TOTAL	1.0 BILLION	TOTAL	4.6 BILLION

SOURCE: AEROSPACE INDUSTRIES ASSOCIATION

use of CAD/CAM systems could increase productivity by a ratio of 2:1 up to 15:1. Figure 2-13 shows the production cost distribution of manufacturing labor. Introduction of a flexible manufacturing system would increase the proportion of labor costs spent on engineering, while reducing fabrication costs as well as some assembly costs. Figure 2-14 shows the cost distribution for the manufacture of commercial airplanes.

Role of Technology in the Long-Term Strategic Outlook

The aerospace industry is currently characterized by impressive growth in new technologies for aircraft materials, design, and manufacture, as well as in how planes are flown. "Aeronautics technology is not yet mature in the sense of reaching diminishing returns for efforts expended . . . the prospective advances of the 1990s far exceed the evolutionary improvements of the 1970s and 1980s in improved capabilities" (Ref.1). In addition, demand should rise for a new generation of quieter, more technically advanced aircraft to replace planes currently growing unprofitable or obsolete. For these reasons the U.S. aircraft manufacturing industry is defined as a sunrise industry.

Marchetti, of the International Institute for Applied Systems Analysis in Laxenberg, Austria, has made projections for the growth in air traffic for the U.S. based on historical trends. According to Marchetti, U.S. passenger air traffic will tend to increase at nearly a 5% annual growth rate. Marchetti's logistic S-curve for growth in air traffic is portrayed in Figure 2-15. Marchetti also points out that as air traffic increases, capacity and efficiency (aircraft productivity) undergo a parallel increase. This trend is portrayed in Figure 2-16.

New technological advances in the aerospace industry can be separated into six categories:

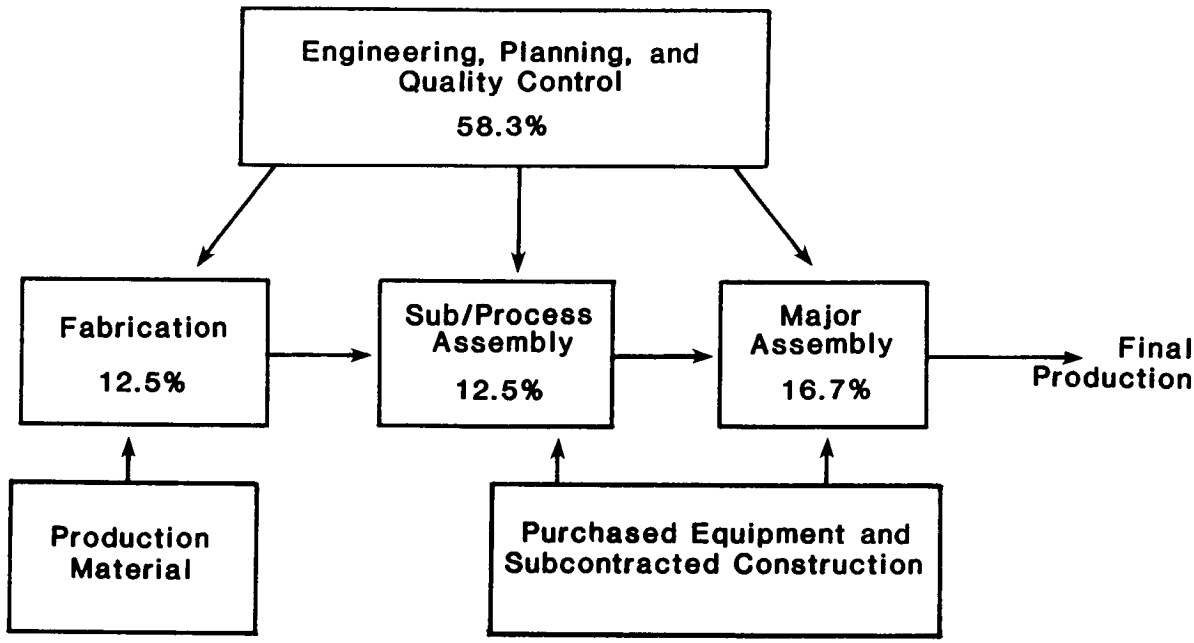
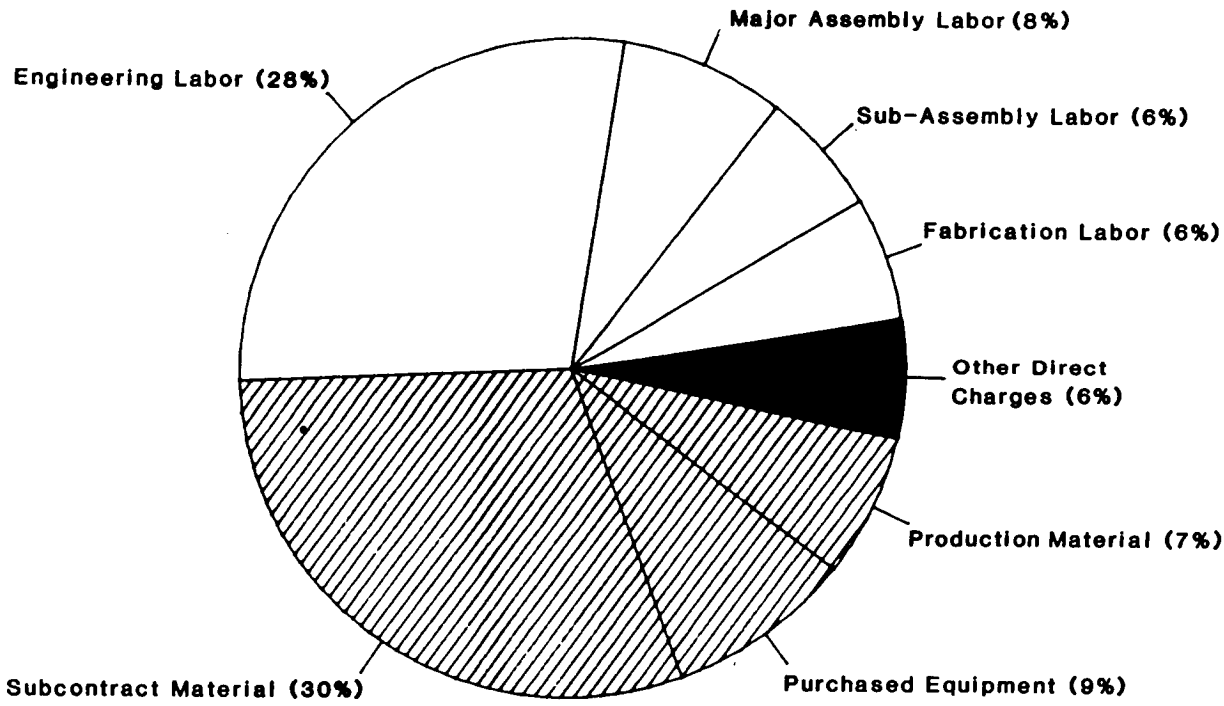


Figure 2-12. Commercial Airplane Production Process: Average Manufacturing Labor Cost Distribution



Source: Boeing Industry Data

Figure 2-13 Commercial Airplane Cost Distribution - Average Airplane Based On First 200 Shipments

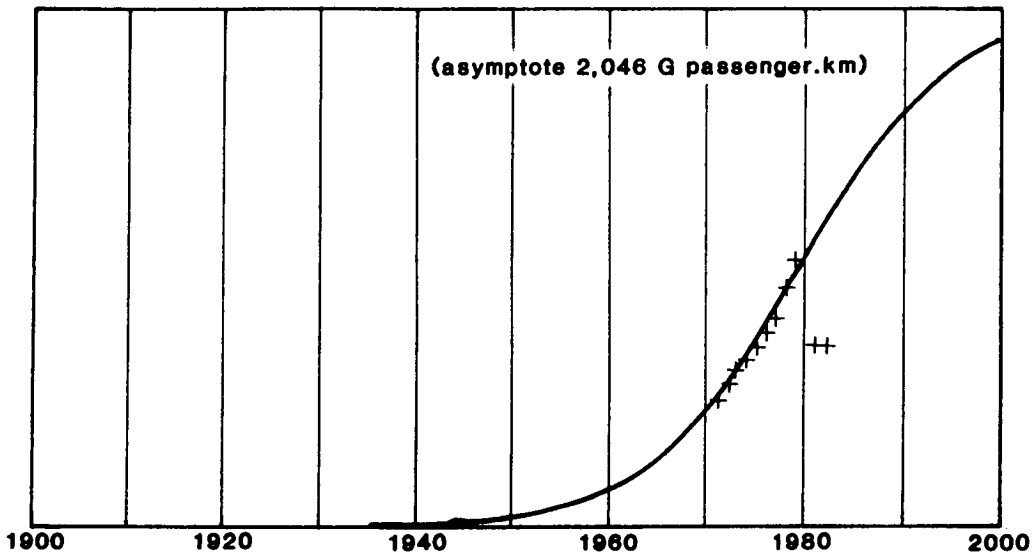


Figure 2-15. IATA Worldwide Passenger-Km Air Growth Logistic 1970 - 1982

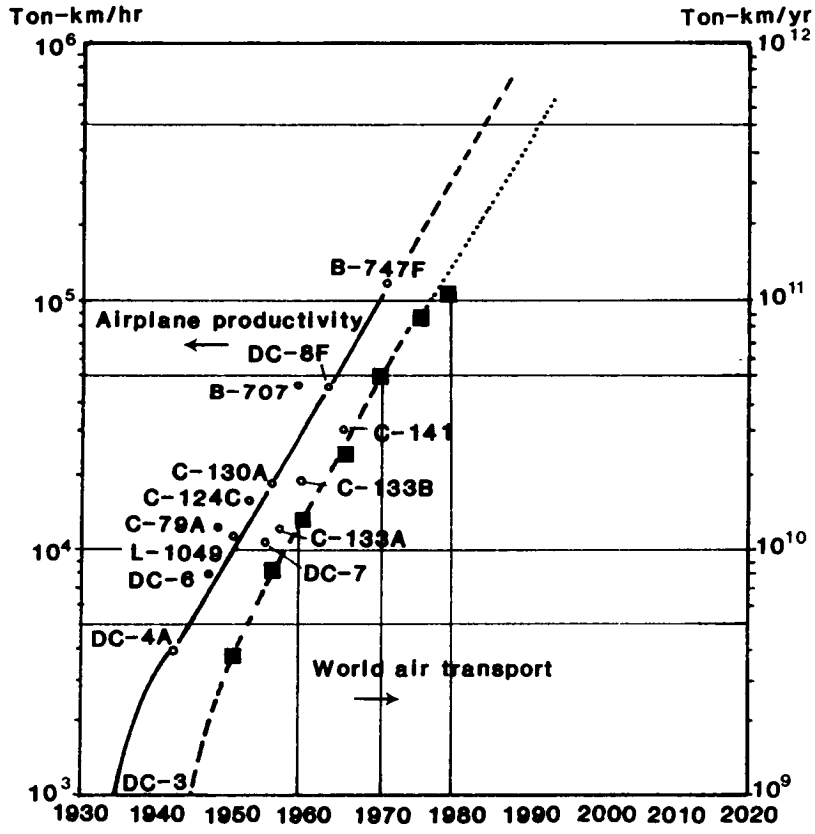


Figure 2-16. Parallel Increase of Air Traffic and of Airplane Productivity

- Aerodynamics,
- Structures and materials,
- Propulsion,
- Avionics,
- Flight controls, and
- Subsystems.

These technologies and their approximate era of diffusion are summarized in Table 2-16. While most of these technologies apply to all types of aircraft, those that apply to a particular aircraft type will be noted as such. In the following subsectors, these new technologies will be considered primarily for application by large, commercial aircraft (over 200 passengers).

Aerodynamics

Aerodynamics advances in aerodynamics include new computational methods and new flow control surfaces. "Computational aerodynamics could not enter a period of rapid development until the later 1960s when computers capable of solving the Navier-Stokes equations by finite difference techniques became available" (Ref. 2). Computational fluid dynamics are separated into the following four categories, based on their levels of sophistication.

- Stage 1--linearized inviscid equations for attached airflows subsonic aircraft including boundary layer and vortex influences (in use for the past ten years).

- Stage 2--inviscid nonlinear equations for subsonic, transonic, and hypersonic airflows including boundary layer effects (used for aircraft design since the late 1970s, although not yet mature).

TABLE 2-16

NEW AEROSPACE TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT	APPROXIMATE ERA OF SIGNIFICANT DIFFUSION
COMPUTATIONAL AERODYNAMICS			
• STAGE 1	LINEARIZED INVISCID COMPUTATIONS FOR ATTACHED AIRFLOWS FOR SUBSONIC AIRCRAFT INCLUDING VORTICES AND BOUNDARY LAYER INFLUENCES.	AIRCRAFT DESIGN, FLOW VISUALIZATION.	
• STAGE 2	NONLINEAR INVISCID (EULER) COMPUTATIONS INCLUDING TRANSONK AND HYPERSONIC FLOWS, AND BOUNDARY LAYER INFLUENCES.	AIRCRAFT DESIGN, TURBULENT FLOW REDUCTION, FLOW VISUALIZATION.	
• STAGE 3	REYNOLDS AVERAGED NAVIER-STOKES COMPUTATIONS THAT CAN INCLUDE SEPARATION, LARGE ANGLES OF ATTACK, UNSTEADY FLOWS, EXTERNAL AND ENGINE FLOW INTERACTIONS.	AIRCRAFT DESIGN, TURBULENT FLOW REDUCTION, FLOW VISUALIZATION.	
• STAGE 4	FULL NAVIER-STOKES CAPABILITIES TO COMPUTE TURBULENCE. CAN INCLUDE AERODYNAMIC NOISE, TRANSITION, SURFACE PRESSURE FLUCTUATIONS, AND TURBULENE INTENSITIES.	AIRCRAFT DESIGN, TURBULENT FLOW REDUCTION, FLOW VISUALIZATION.	
LAMINAR FLOW CONTROL TECHNOLOGY			
• NATURAL LAMINAR FLOW	LAMINAR FLOW OVER WING AND FUSELAGE RESULTING FROM SMOOTHER SURFACE FINISH ON MODIFIED WING STRUCTURE.	TRANSPORT AIRCRAFT 30% FUEL SAVINGS/ RANGE EXPANSION.	
• MECHANICALLY INDUCED LAMINAR FLOW	SMALL HOLES ON LEADING EDGE OF WING ALLOW TURBULENT BOUNDARY LAYER TO BE REMOVED.	TRANSPORT AIRCRAFT 30% FUEL SAVINGS/RANGE EXPANSION.	
STRUCTURES AND MATERIALS			
• ALUMINUM TITANIUM ALLOY	LIGHT WEIGHT, HIGH STRENGTH ALUMINUM ALLOY.	REDUCE STRUCTURAL WEIGHT.	
• EPOXY	LIGHT WEIGHT, HIGH STRENGTH RESIN MATRIX MATERIAL.	REDUCE STRUCTURAL WEIGHT.	
• ADVANCED FIBER EPOXY	LIGHT WEIGHT, HIGH STRENGTH RESIN MATRIX MATERIAL.	REDUCE STRUCTURAL WEIGHT.	
• POWDERED METALS	ALLOWS PRODUCTION OF UNUSUAL ALLOYS AND SUPERALLOYS.	REDUCE STRUCTURAL WEIGHT IMPROVE STRENGTH TO WEIGHT RATIO OF CERTAIN METALS.	
• THERMO PLASTICS/ ADVANCED EPOXIES	HIGH TEMPERATURE, LIGHT WEIGHT, HIGH STRENGTH COMPOSITES.	REDUCE STRUCTURAL WEIGHT, INCREASE STRENGTH.	
• METAL MATRIX COMPOSITES	HIGH TEMPERATURE, LIGHTWEIGHT, HIGH STRENGTH METAL MATRIX COMPOSITES: CARBON OR CARBIDE FIBERS IN METAL MATRIX.	REDUCE STRUCTRUAL WEIGHT.	
• CERAMICS	HIGH TEMPERATURE, HIGH STRENGTH ENGINE COMPONENTS.	REDUCE WEIGHT, INCREASE THERMAL EFFICIENCY.	

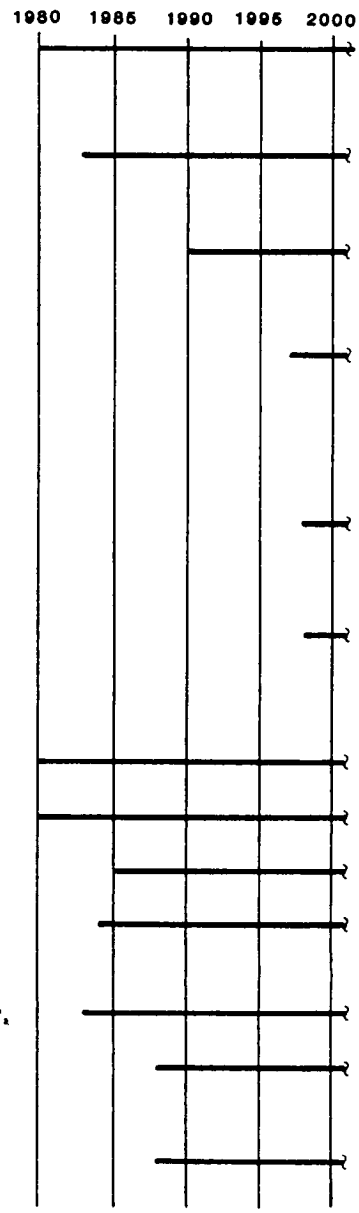
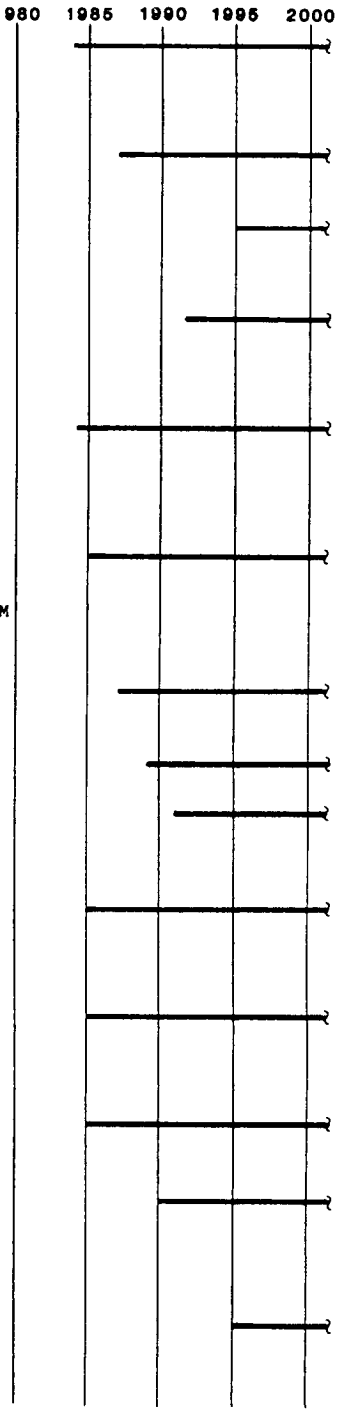


TABLE 2-16 (CONT'D)

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT	APPROXIMATE ERA OF SIGNIFICANT DIFFUSION
PROPULSION			
• ADVANCED HIGH BYPASS RATIO TURBOFAN CF6-80C PW2037 (JT10D)	ADVANCED TURBOFAN ENGINE ENCASED IN MORE AERODYNAMIC NACELLE FEATURING DIGITAL BLADE CLEARANCE CONTROL.	REDUCE NOISE 5dB, REDUCE SPECIFIC FUEL CONSUMPTION 12% (1980 BASELINE), IMPROVE RELIABILITY AND DURABILITY.	
• DIRECT DRIVE HIGH BYPASS RATIO TURBOFAN	ADVANCED TURBOFAN ENGINE (BPR=5.5) WITH DIRECT DRIVE COMPRESSOR.	REDUCE NOISE, REDUCE SPECIFIC FUEL CONSUMPTION 15%.	
• GEARED HIGH BYPASS RATIO TURBOFAN	ADVANCED TURBOFAN ENGINE (BPR=9) WITH GEAR DRIVEN COMPRESSOR FOR BETTER MATCH BETWEEN TAKEOFF AND CRUISE THRUST.	REDUCE NOISE, REDUCE SPECIFIC FUEL CONSUMPTION 20%.	
• HIGH SPEED TURBOPROP (MACH 0.72 TO 0.8)	ADVANCED HIGH SPEED, HIGHLY SWEPT, MULT-BLADED TURBO PROP.	REDUCE SPECIFIC FUEL CONSUMPTION 30%.	
AVIONICS AND CONTROLS			
• FULLY DIGITAL FLIGHT MANAGEMENT SYSTEM (FMS)	FMS INTEGRATES INSTRUMENT OUTPUTS, COMMUNICATIONS, ENGINE, AND ENVIRONMENT CONTROLS AND AND PROVIDES PILOT WITH WARNING FOR DANGEROUS TRANSIENTS.	REDUCE CREW WORKLOAD, IMPROVE CREW EFFICIENCY, ELIMINATES NEED FOR TWO CREW MEMBERS FOR COPILOT AND COMMUNICATIONS	
• FIBER OPTICS	REPLACE ELECTRICAL SYSTEM WIRE LINKS WITH FIBER OPTICS.	REDUCE ELECTRICAL SYSTEM WEIGHT, INCREASE TRANSMISSION SPEED 1000 TIMES, ELIMINATE ELECTRICAL SYSTEM SUSCEPTIBILITY TO ELECTROMAGNETIC INTERFERENCE.	
• MICROWAVE LANDING SYSTEM	FAA-DEVELOPED AIRPORT TRAFFIC AND/AIRCRAFT NAVIGATION AID.	REDUCE CREW WORKLOAD, REDUCE AIRPORT DELAYS AND AIR TRAFFIC LOADS.	
• FLAT PANEL CATHODE RAY TUBE (CRT)	FLAT PANEL FLIGHT INFORMATION DISPLAY FOR IMPROVED RESOLUTION.	REDUCE COCKPIT CLUTTER REDUCE CREW WORKLOAD.	
• ALL ELECTRIC CONTROLS	ELECTRIC ACTUATORS.	ELIMINATE HYDRAULICS, REDUCE WEIGHT, REDUCE COCKPIT CLUTTER BY ELIMINATING STEERING YOKES.	
• INTEGRATED VLSI/VHSIC	VERY LARGE INTEGRATION (VLSI) OF INSTRUMENTS AND CONTROL UTILIZING VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC).	IMPROVE WEIGHT TO POWER RATIO 80%, REDUCE CREW WORKLOAD TENFOLD IMPROVEMENT IN RELIABILITY OF SIGNAL PROCESSING.	
• ADVANCED BRAKES/ STEERING	LIGHTWEIGHT CARBON BRAKES COMPOSITE STEERING STRUCTURE.	REDUCE RUNWAY LENGTH REQUIREMENTS.	
MANUFACTURING SYSTEMS			
• SPIN FORGING	TWO SPINNING ROLLERS SHAPE SPINNING WORK PIECE (FOR SOLIDS OF REVOLUTION).	REDUCE COMPONENT WEIGHT REDUCE ADDITIONAL MACHINING	
• FLEXIBLE MANUFACTURING	AUTOMATED WORK CELL CONSISTING OF COMPUTERIZED NUMERICALLY CONTROLLED MACHINING OPERATIONS WITH ROBOTICS TRANSFER MECHANISMS--ADAPTABLE TO SMALL BATCH PROCESSES.	INCREASE PRODUCTIVITY.	
• INTEGRATED MANUFACTURING SYSTEM	FMS WITH DIRECT LINK TO CAD COMPUTERS.	INCREASE PRODUCTIVITY, ENABLE DESIGNER TO UPGRADE PART DESIGN WHILE ON-LINE.	



- Stage 3--viscous Reynolds averaged Navier-Stokes equations to include separated flows, unsteady flows, large angles of attack, and external and engine flow interactions (limited use, although extensively researched; available in mature form during 1990s).

- Stage 4--full Navier-Stoke capabilities to compute rather than model turbulence including aerodynamic noise, transition, surface press and turbulence intensity fluctuations (currently being researched) (Ref. 2).

The benefits of the industrial use of computational fluid dynamics are reduced wind tunnel and flight tests costs, improved aerodynamics, a better understanding of fluid dynamics, and better designs based on turbulent flow reduction. The leading user of computational fluid dynamics is the turbine engine manufacturing industry.

Another exciting area of aerodynamics is the design and development of drag reducing external structures, such as laminar flow airfoils and conformal weapons carriages (for fighters and military helicopters). Laminar flow control technology, when applied to long-range wide-body commercial aircraft, could result in a 20% to 40% reduction in fuel consumption. Turbulent drag is reduced on a laminar flow wing by sucking low-energy boundary layer air through small holes in the leading edge (first 10% of chord length) of both upper and lower wing surfaces, which keeps the air flow attached to the wing and delays the onset of turbulent separation. Both Lockheed and McDonnell Douglas have tested this technology with NASA at the Ames-Dryden Flight Research Center. High aspect ratio wings (aspect ratio is the ratio of length to chord length) may also save fuel for long-range commercial aircraft.

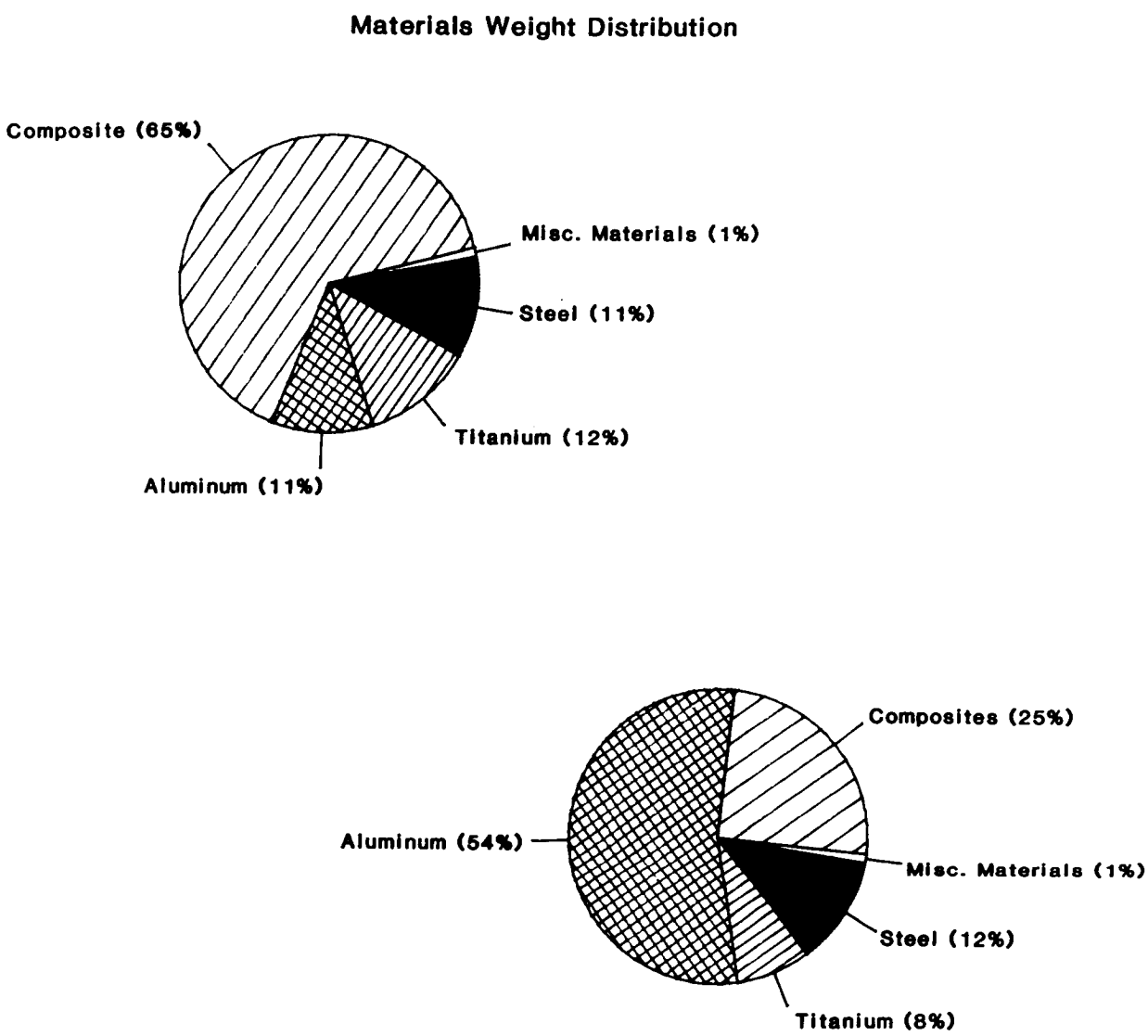
Aerodynamic improvements on fighters serve a dual purpose: to reduce drag and improve maneuverability, and to lower the aircraft's radar cross-section. Adaptive wing contouring for fighters could improve the supersonic lift-to-drag ratio 100%. Airfoils and fuselages modeled with computational fluid dynamics can be designed for vortex control, which would double the conventional fighter's maneuverability. Finally, shaping a fighter for a low radar profile also enhances the aircraft's aerodynamics.

Structures and Materials

Weight reduction is a key goal in aircraft manufacturing. Over a commercial aircraft's 20 year operating lifespan, each pound shaved from a plane's weight could result in fuel savings of $500 per year. Approximately half of a transport aircraft's weight is made up of structural components, while the other half is made up of subsystem weight. This subsection will be devoted to analyzing weight reduction and other benefits associated with applying advanced technology to structural components; the benefits associated with subsystem weight reduction will be considered in the controls subsection.

The current commercial aircraft's structural weight consists of about 80% aluminum, 15 to 20% steel and titanium, 3% composites, and about 1% miscellaneous materials. Use of composites such as carbon-fiber reinforced resin matrix materials, polyimides, fiberglass, and others should rise to at least 30% of aluminum's proportion. Other materials that may replace aluminum are lighter weight, higher strength metal matrix materials (such as aluminum-lithium alloys), and aluminum-lithium-aramid laminates. Two projections concerning the increased use of composites or advanced aluminum alloys are portrayed in Figure 2-17.

Composites are already being utilized for some aft fuselage and elevator components. Further use of composites must be



Source: John E. Steiner
Air Technology: The Transport Vehicle
and its Development Environment

Figure 2-17. Potential Use of Advanced Materials in Subsonic Airplane Production

weighed against the use of aluminum alloys. One advantage of composites is that they can be formed into molds according to the required size and shape of components, which minimizes the amount of waste material created during production. Another advantage is that larger and simpler parts may be manufactured, thus reducing the need for fasteners while making assembly simpler. The fiber layout in composites may be specified to provide strength in the direction of stress distribution. A further advantage of composites is their low radar cross-section in comparison with metals. A semi-porous carbon fiber composite would be an important component of laminar flow control wings, which would result in lower production costs (electron beam drilling would not be needed) and lower maintenance costs.

A significant disadvantage of composites as compared to advanced alloys derives from short-term higher production costs, and from uncertainties concerning material strength and integrity. In order to utilize composites, production personnel must be retrained and production machinery retooled. In addition, some composites demonstrate reduced structural integrity caused by low velocity impacts from runway debris, rocks, and hailstone.

Aluminum alloys have been created with increased strength and reduced weight through powdered metal technology. Current alloys offer up to 50% weight reductions compared to aluminum. Although this weight reduction is not as great as is possible with composites, aluminum alloys demonstrate several comparative advantages. Metals typically have lower materials costs than composites. Use of advanced alloys allows conventional forms (sheet, plate, extrusions, forgings) to be used along with conventional design and manufacturing methods and current maintenance facilities and techniques. Expensive retooling and retraining would not be needed to produce aluminum alloys. Finally, analysis and use of metal alloys are simplified because of their isotropic properties.

Metal composites combine the benefits of metals and composites. Some of these materials are metal-matrix composites consisting of aluminum matrices reinforced with graphite, boron, alumina, or silicon carbide fibers. Metal fiber laminates also fall under this category. An example of a metal fiber laminate is Arall, which consists of 0.4mm aluminum alloy sheets bonded with 0.2mm layers of resin-based adhesive impregnated with unidirectional aramid fibers. Metal composites have most of the same advantages as aluminum alloys including resistance to corrosion and creep. Metal-composite laminates are especially resistant to creep since crack propagation is halted by the various laminate layers, although delamination could pose problems. Arall has a yield stress and ultimate tensile strength higher than aluminum alloys, while its weight is 30 to 40% less than aluminum alloys, and its impact strength is far superior to carbon fiber composites. Composite materials of comparable thickness and strength would cost two to three times as much as Arall, although Arall is more expensive to produce than monolithic aluminum alloys.

According to Laurens B. Vogelsang, professor of advanced materials at the Delft University of Technology, "If weight savings of 17% can be achieved, it is cost effective to replace aluminum alloys with Arall " (Ref. 3). Professor Vogelsang foresees the future aircraft as a combination of advanced materials: metals for engines and main wing components, Arall for fuselage and underwing panels, and composites for wing leading and trailing edges. Figure 2-18 shows future structural materials that will continue the weight saving trend.

The addition of titanium and steel to the structural weight of commercial airplanes will not likely decrease in the future. Potential cost savings for this portion of the plane's weight arise from cheaper manufacturing technologies. Explosive forming and bonding rely on the property of superplasticity exhibited at high temperatures by titanium and its alloys. Superplasticity is

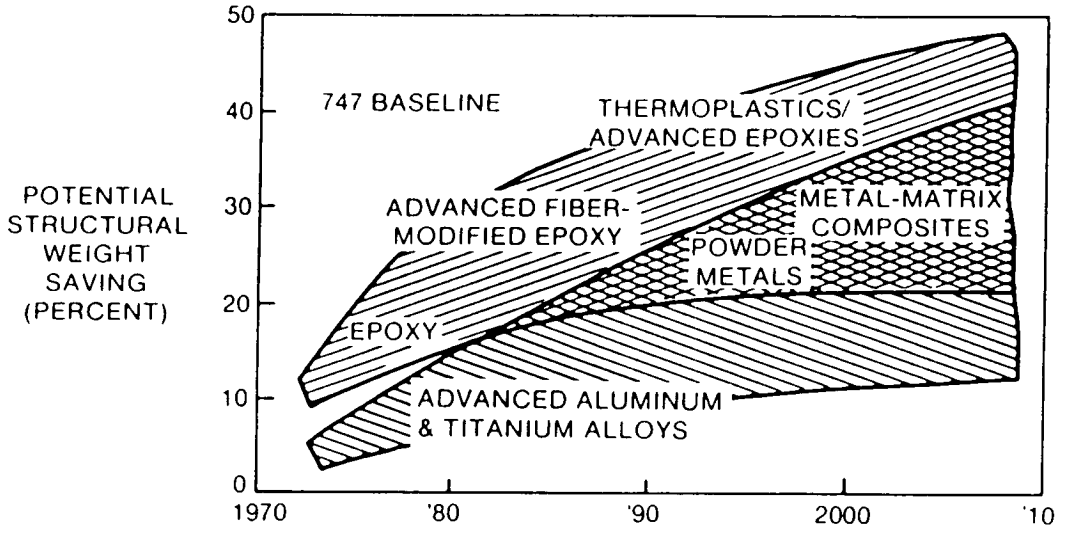


Figure 2-18. Future Structural Materials Trend for Potential Weight Savings

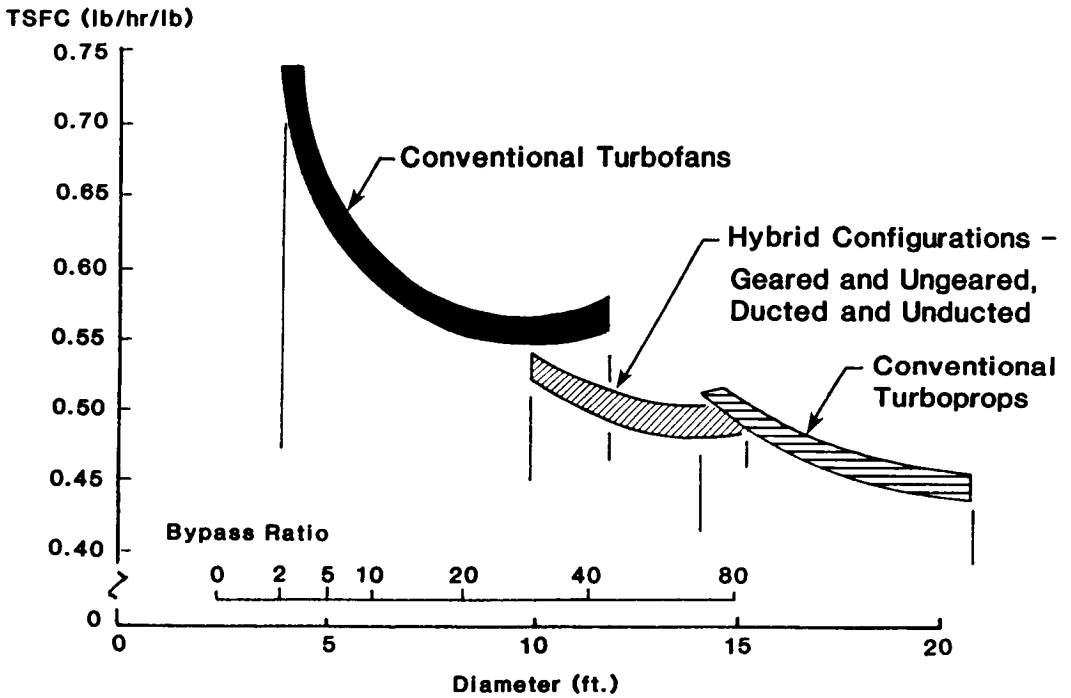


Figure 2-19. Specific Fuel Consumption Engine Size Trends

the ability of a material to be elongated extensively without localized thinning or rupture. Explosive forming and diffusion bonding at high temperatures could result in 10 to 15% weight reductions (without strength reduction), and in cost savings approaching 50% as a result of reduced machining and fastener use.

Another cost and machining reducing technology is spin-forging. Spin-forging reshapes a die-forged preform by driving two heavy, spinning rollers into the spinning preform at a precise, computer-controlled rate. Spin-forged parts require less machining to meet dimensional and surface finish requirements. The Aluminum Company of America (Alcoa) produced a turbofan engine nose cap that was 30% lighter than the pressed or die-forged counterpart. Spin-forging also enables the manufacture of parts with tapered thicknesses or special contours unavailable by conventional methods.

Propulsion

The high bypass ratio (BPR) turbofan should continue to power large, intercontinental-range subsonic transport aircraft through the end of this century. Engine efficiencies are expected to increase 20% per decade during this time. Since the introduction of the low bypass ratio turbofan in the early 1960s, 40% improvements in total specific fuel consumption, as well as the corresponding gains in engine efficiency, resulted from increases in bypass ratio (along with increases in diameter). Figure 2-19 shows that as bypass ratio increases, the total specific fuel consumption (TSFC) decreases. Future gains should be less dependent on increasing BPR, since higher BPR implies larger, heavier nacelles while contributing to a mismatch between takeoff and cruise thrust requirements.

The overall engine efficiency is the product of the thermal and the propulsive efficiencies. For future turbofans, the ther-

mal efficiency will increase as a result of increased overall pressure ratios, higher component efficiencies, and higher combustor exit temperatures. The propulsive efficiency will also rise as low drag nacelles are developed, and as a result of some increases in BPR. In order to offset the incongruity between takeoff and cruise thrust caused by high BPR, new engine designs will move toward a geared cycle engine, an advance that that will enable the development of hybrid configurations, including unducted fans and turboprops.

The turbofan engine should also evolve better thrust to weight ratios as light weight materials are used to replace metals in engine components. Composites will be used for engine cases and support structures, as well as some internal applications, including rotor blades. High temperature polyimide-resin matrix materials have been applied to the core cowl and acoustic barrel of a conventional turbofan exhaust nozzle. Ceramics offer myriad potential benefits if applied to the turbine section, although their reliability and durability must be improved before utilizing them in such a high risk application. Potential benefits of ceramics are higher strength at higher temperatures ($2500^{o}F$, or a 30% increase over super-alloy operating temperatures), one third lower density than superalloys, greater corrosion resistance, lower cost, and their availability from domestic resources (whereas the majority of strategic metals, that they would replace such as chromium, cobalt, etc., are imported). Ceramic components are also easier to produce than machining, extremely tough metals and have a better surface finish. Engines composed of composites and ceramics also have lower radar cross-sections for stealth applications.

The turboprop offers even greater increases in propulsive efficiency since it can utilize low fan pressure ratios (across the propeller) without the massive nacelles that would be required for a turbofan to achieve the same low fan pressure ratio. In order to compete with other forms of commercial trans-

portation aircraft, the turboprop engined aircraft must be able to achieve higher speeds (mach 0.8). Propellers for these applications would have multiple thin, highly swept blades. Provided turboprop engine development continues at its present rate, these engines will be ready for testing by 1987, and ready for installation on medium-range transports by the early 1990s. Turboprop engines offer potential fuel savings of 20% over turbofans. Adding counter-rotational propellers to the turboprop configuration to reduce swirl would result in about 7% additional fuel savings.

Small aircraft engines under investigation include diesel, rotary, and turboprop types. Potential supersonic propulsion improvements are not being pursued as aggressively.

Avionics

Advances in avionics will help to bring about the all electric airplane in which all data and controls are digitized. By integrating instrument outputs through very large scale integration (VLSI) with very high speed integrated circuits (VHSIC), the weight to power ratio for these components will decrease 70 to 80%, while reliability of signal processing will increase by a factor of ten. Data will be transmitted 1000 times faster via optic fiber, which also reduces weight and makes signals invulnerable to electromagnetic interference (EMI) or, for military applications, to an electromagnetic pulse (EMP). On-board computers will integrate these data for automatic trajectory and attitude control, thus reducing crew work load. Data from improved ground aids such as microwave landing systems and wind shear detectors will also be integrated with other flight data. At the core of this combined flight management system (FMS) is the inertial reference system defined by a laser gyro.

Data from the FMS will be displayed on several new space and weight saving devices. Flat panel cathode ray tubes (CRT) are

already in use on military fighters as well as in the European Airbus Industry's A320. Holographic "head up" displays will make information readily available to the flight crew while performing a maneuver, by displaying the information on the canopy in front of the pilot.

Other advantages of advanced avionics should not only relieve crew work load, but may well eliminate the need for a third crew member. Digitized voice communications will greatly simplify the communications officer's job. Navigation will also be simplified. Engine and environment controls will also be managed by the FMS for energy use optimization resulting in an increase in range by from 4 to 8%. The military could benefit even more from active and passive electronic sensors integrated with VLSI/VHSIC, which would result in improved lethality and survivability.

Flight Controls

The most noticeable aspect of electric controls will be in the elmination of weight and complexity. Solid state electromagnetic actuators will eliminate pneumatic systems. Another advantage of replacing pneumatics with electric controls, in addition to reducing weight, is the elimination of bleed air requirements from turbofan compressors. Electric controls will replace heavy control yokes with much lighter toggle switches or joysticks. All electric controls should reduce structural weight by 10%.

Active control technology is an integral part of the flight management system (FMS). A benefit of integrating active control technology with current aircraft technology is a stabilized plane during static or relaxed controls flying. Potential benefits of integrating active control with new structures, materials, and engines could result in even greater fuel savings as plane's control surfaces are reduced along with aerodynamic drag.

Another important factor in utilizing all electric controls is their price. Conventional analog devices are very expensive in comparison with the cost of simple transducers coupled with microprocessor integrated circuits required for a digitized flight information system.

Subsystems

The switch to fully electric flight and environment controls is much better suited for the planes of the next few decades than hydraulic systems. Electric circuits and controls are much simpler and cheaper than hydraulics. Electric power is ideally suited for being extracted from the turbine shaft work, whereas compressor air bled for pneumatics detracts from turbofan performance. Electronics are also easier to maintain and replace.

Other subsystem advances that could improve aircraft performance are: 1) advanced brakes and steering systems will decrease runway length requirements; 2) advanced power distribution will directly benefit digital flight controls; and 3) closed loop environment controls will make military aircraft less susceptible to chemical warfare.

Conclusion

Technology improvements are occurring in all sectors of the aircraft industry. "The many possibilities in the propulsion area are ample demonstration that the potentials in aeronautics will clearly outweigh the resources available for development." (Ref. 4) Industry officials are seeking government support for the focused development of various sectors of the aircraft industry. There are no "leapfrog" technologies per se; rather the benefits resulting from one advanced technology can be enhanced by integrating it with others. Benefits are optimized by integrating all of the advances in various fields into the future aircraft. These integrated benefits for large transport aircraft are summarized below:

- 30% increase in productivity,
- 50% increase in payload and range,
- 30% reduction in life cycle costs, and
- reduced operating costs--$9 billion less for 100 plane fleet over 20 years.

For military fighters, the integrated benefits are as follows:

- 20:1 improvement in effectiveness due to increased lethality and survivability in surface-to-air and air-to-air missile environment by implementing the most advanced technologies for stealth,
- 2:1 improvement in availability,
- 25% reduction in life cycle costs, and
- $14 billion less for 1000 plane fleet over 20 years.

New aerospace technologies and their approximate era of diffusion are summarized in Table 2-16.

In order to maintain a competitive posture against foreign, government-subsidized aircraft manufacturers, the U.S. aircraft industry, in conjunction with the federal government, must establish a set of goals for both the near-term and the long range future aircraft development and marketing. These goals include:

- The establishment of a timely and proven technology base, and

- The establishment of a government policy with respect to competing foreign industries that assures fairness in and access to both domestic and foreign markets.

The emphasis of this subsection has been on advanced technologies; recommendations on government policy are beyond the scope of this report.

Development of an advanced aircraft technology data base is best suited for NASA. The DOD research is focused on near-term applications, while NASA should focus its research efforts on long lead, high-risk technology. Thus, NASA's budget should be expanded in order to research technologies that advance the state-of-the-art in the following fields:

- Advanced materials--especially to develop a manual of standards for exsisting composites, alloys, etc.;

- Advanced engines--capable of burning currently available as well as future aviation fuels;

- Flexible computer-aided manufacturing systems as well as coupled CAD/CAM systems--in-depth evaluation of available alternatives and manufacturing process risks and acceptability levels;

- Advanced aerodynamics--particularly computational fluid dynamics;

- Hypersonic flight--wind tunnel facilities and advanced experimental aircraft for actual flight testing;

- Advanced electronics and avionics--the all electric aircraft, navigational aids, and active controls.

Research in these fields is aided by achieving an understanding of the integration of the most advanced technology in an aircraft for optimum performance in the aircraft's designated task. NASA should also develop a viable mechanism for effective control of technology transfer as well as for exploiting foreign R&D.

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B.3 "ELECTRICAL AND ELECTRONIC MACHINERY" (SIC 36)

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SOURCES: EOP/OMB:

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U.S. DOC/BIE:

SOURCES: U.S. DOL/BLS
(Cont'd) Arthur D. Little, Inc.
Value-Line Investment Survey, 1984

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B.3 "ELECTRICAL AND ELECTRONIC MACHINERY" (SIC 36)

The electrical and electronic industry subsector, SIC 36, is the third largest manufacturing subsector in the U.S. In 1980, the value added of this subsector contributed 9.4% of the manufacturing sector's contribution to GDP. The subsector is characterized by:

- A high degree of fragmentation. Out of a total of approximately 15,000 establishments, 9,000 employed less than 20 persons (1977).

- A labor productivity of $20,883 per employee year or $10.88 per employee hour (1980, 1972 $), ranking this subsector eleventh among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 1.6%/year from 1972 to 1980 ranks this subsector seventh. The labor productivity for the comparable Japanese subsector was $11,875 per employee year or $6.18 per employee hour (1980, 1972 $), ranking this subsector tenth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 4.4%/year from 1972 to 1980, ranking this subsector fifteenth.

- A lower than average capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $10,127 in total assets per worker, ranking fifteenth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $1,759 per employee (1980, 1972 $), ranking tenth in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment, was 0.94 (1981).

- A very aggressive R&D program. For the subsector as a whole, R&D expenditures amounted to $5.1 billion (1980, 1972 $), ranking this subsector second among the 20 manufacturing subsectors. R&D expenditures were equivalent to 12.1% of the value added by the subsector in (1980, 1972 $).

- Smaller establishments principally devoted to the production of limited lines of electronic components, whereas the larger ones produce components, subassemblies, subsystems as well as final commercial and/or military products.

Table 3-1 shows the major products produced by each subdivision of the electrical and electronic machinery subsector ranked in descending order of contribution to manufacturing's share of the GDP in 1980. Table 3-2 summarizes the principal economic measures of the industry's subdivisions according to the 1981 Annual Survey of Manufactures.

Two subdivisions--Communication Equipment (SIC 366) and Electronic Components and Accessories (SIC 367)--accounted for 54.0% of the subsector's contribution to the GDP in 1980. Since these subdivisions are also the most advanced technologically, they have been selected for further analysis.

B.3.1 COMMUNICATION EQUIPMENT SUBDIVISION (SIC 366)

The communication equipment subdivision produces a wide range of products and systems. Principal among these are:

- telephone and telegraph equipment;

- radio and television broadcast equipment;

- communication satellites;

TABLE 3-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE ELECTRICAL AND ELECTRONIC MACHINERY INDUSTRY (SIC 36) AND CONTRIBUTION TO SUBSECTOR IN 1980

SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
366	**COMMUNICATION EQUIPMENT** TELEPHONE AND TELEGRAPH APPARATUS, RADIO AND TV TRANSMITTING, SIGNALING, COMMUNICATION RELAYS, AND DETECTION EQUIPMENT AND APPARATUS.	30.9
367	**ELECTRONIC COMPONENTS AND ACCESSORIES** CATHODE RAY TUBES, TRANSMITTING, INDUSTRIAL AND SPECIAL PURPOSE TUBES, SEMICONDUCTORS AND RELATED DEVICES, ELECTRONIC CAPACITORS, RESISTORS, ELECTRONIC COILS AND CONNECTORS, AND ELECTRON TUBES.	23.1
362	**ELECTRICAL INDUSTRIAL APPARATUS** MOTORS AND GENERATORS, INDUSTRIAL CONTROLS, WELDING APPARATUS, AND CARBON AND GRAPHITE PRODUCTS.	10.4
364	**ELECTRIC LIGHTING AND WIRING EQUIPMENT** ELECTRIC LAMPS, CURRENT-CARRYING WIRING DEVICES, NONCURRENT-CARRYING WIRING DEVICES, LIGHTING FIXTURES, AND VEHICULAR LIGHTING EQUIPMENT.	8.4
363	**HOUSEHOLD APPLIANCES** HOUSEHOLD COOKING EQUIPMENT, HOUSEHOLD REFRIGERATORS, HOME AND FARM FREEZERS, HOUSEHOLD LAUNDRY EQUIPMENT, ELECTRIC HOUSEWARES AND FANS, HOUSEHOLD VACUUM CLEANERS, AND SEWING MACHINES.	8.2
369	**MISCELLANEOUS ELECTRICAL MACHINERY EQUIPMENT** STORAGE BATTERIES, PRIMARY BATTERIES, X-RAY APPARATUS AND TUBES, ELECTROMEDICAL AND ELECTROTHERAPEUTIC APPARATUS, AND ELECTRICAL EQUIPMENT FOR INTERNAL COMBUSION ENGINES.	7.7
361	**ELECTRIC TRANSMISSION AND DISTRIBUTION EQUIPMENT** TRANSFORMERS, SWITCHGEAR, AND SWITCHBOARD APPARATUS.	6.1
365	**RADIO AND TV RECEIVING EQUIPMENT, EXCEPT COMMUNICATION TYPES** RADIO AND TV RECEIVING SETS, PHONOGRAPH RECORD, AND PRERECORDED MAGNETIC TAPE.	5.2
36	ALL ELECTRIC AND ELECTRONIC MACHINERY	100.0

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1977

TABLE 3-2

SUBDIVISIONS AND CHARACTERIZATION OF THE ELECTRICAL AND ELECTRONIC INDUSTRY (SIC 36) DURING 1980, IN 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	NUMBER OF EMPLOYEES (1000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL ELECTRICAL AND ELECTRONIC (36)	100	1,963.2	14,973	8,635	2,870	10,127	1,759	20,883
ELECTRIC TRANSMISSION (361)	7	117.2	947	488	220	9,531	1,022	21,209
ELECTRICAL INDUSTRIAL APPARATUS (362)	11	210.5	1,646	827	398	10,779	1,340	20,245
HOUSEHOLD APPLIANCES (363)	11	155.2	666	324	224	9,730	1,014	21,614
ELECTRIC LIGHTING AND WIRING EQUIPMENT (364)	9	176.1	2,009	1,096	362	9,697	1,256	19,838
RADIO AND TV RECEIVING EQUIPMENT (365)	6	87.5	1,290	965	138	9,057	1,346	24,161
COMMUNICATION EQUIPMENT (366)	28	566.1	2,385	1,259	539	8,172	1,468	22,358
ELECTRONIC COMPONENTS AND ACCESSORIES (367)	18	498.6	4,455	2,784	668	12,016	12,940	19,000
BATTERIES AND MISCELLANEOUS ELECTRICAL (369)	10	152.0	1,575	892	321	12,289	1,702	20,785

[a] 1977

SOURCE: U.S. DOC/BOC CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: 1981 ANNUAL SURVEY OF MANUFACTURES

- mobile radio;
- radar;
- search and detection equipment;
- and electronic mail equipment.

Telephone and telegraph equipment contributes over one-quarter of the industry's shipment values. The U.S. federal government, specifically DOD, DOT, and NASA, is the major purchaser (over 50%) of electronic systems and equipment. The growth of this industry is influenced by purchase demands from the federal government, and by the communication needs of households and businesses.

The historical and current posture of the communications equipment industry is summarized in Tables 3-3 and 3-4, which highlight its business and operating profiles. Table 3-3 indicates that industry shipments have increased almost 96% during the 1972-1983 period as expressed in constant 1972 dollars, from $13.7 billion in 1972 to $26.8 billion in 1983. The 1984 forcast for shipments is 29.1 billion (1972 $), an increase of 8.6% over 1983. Employment has increased by 31.5%, from 453,600 in 1972 to 596,300 in 1983. Labor productivity in dollars (output per employee hour) has risen steadily since 1958.

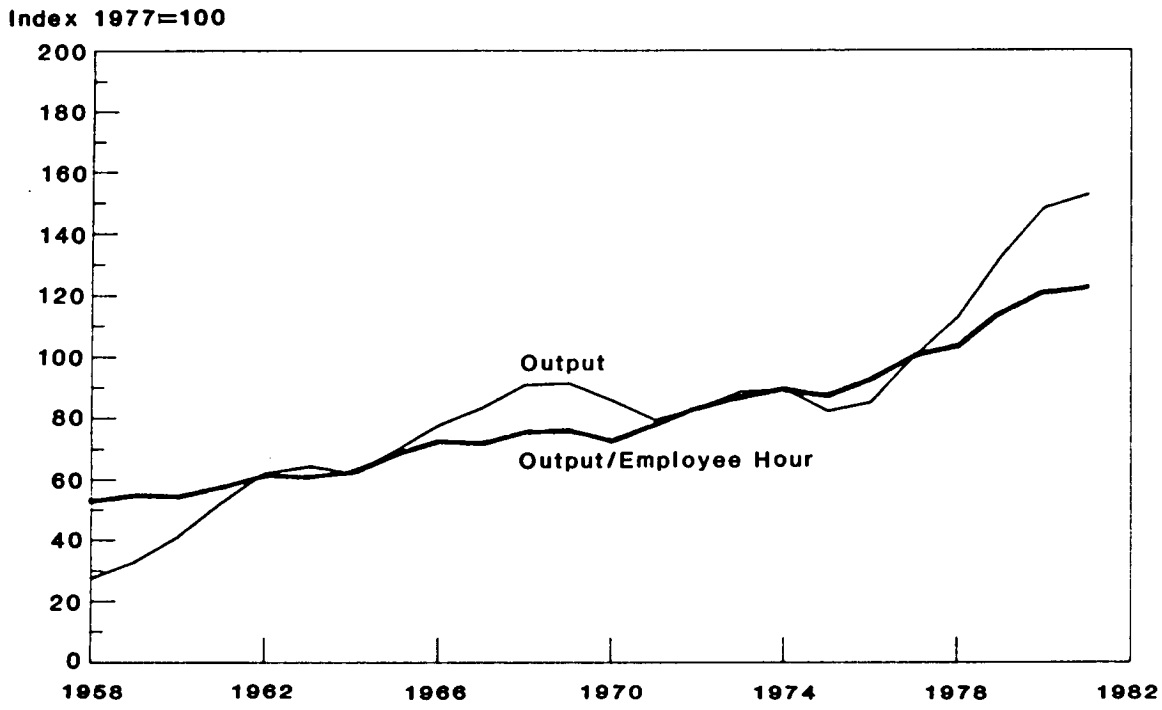
Table 3-4 indicates that the communications equipment industry is comprised of a large number of small firms. The cost of finished products in the industry is dominated by the cost of input materials (43%); manufacturing labor represents 13% of total costs. Other labor accounts for 14% of total production costs, which reflects the large amount of R&D expenditures.

Significant structural changes have occurred in the telephone communications equipment industry in the wake of litiga-

TABLE 3-3

BUSINESS PROFILE OF THE
COMMUNICATIONS EQUIPMENT INDUSTRY (SIC 366)

	1972	1977	1979	1981	1983	1984 EST.
SHIPMENTS (BILLION $)						
CURRENT $	13.7	22.7	30.3	40.4	48.1	62.5
1972 $	13.7	16.2	21.0	24.9	26.8	29.1
TOTAL EMPLOYMENT (THOUSANDS)	453.6	458.5	531.3	574.3	596.3	614.0



Source: Unpublished BLS Data

	1977	1981
NEW CAPITAL EXPENDITURES, CURRENT $, BILLION	0.6	1.9

SOURCES: U.S. DOC/BOC: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SUVERY, 1984
U.S. DOL/BLS

TABLE 3-4

STRUCTURAL PROFILE OF THE
COMMUNICATIONS EQUIPMENT INDUSTRY (SIC 366)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

TOTAL	3,676
SMALL (<20)	2,224
INTERMEDIATE (20-1000)	1,333
LARGE (>1000)	119
TOTAL (2,068 COMPANIES)	3,676

LEADING FIRMS (1983)

NAME	DOMESTICALLY GENERATED SALES ($ MILLION)
AT&T	3,500
GTE	2,704
MOTOROLA	1,249
TEXAS INSTRUMENTS	1,099
M/A-COM, INC.	637
AMERICAN DISTRICT TELEPHONE	480
ROLM	432

	MFG. LABOR	OTHER LABOR	MATERIAL	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	13%	14%	43%	1%	29%

R&D EXPENDITURES, CURRENT $, BILLION

	1977	1979	1981
TOTAL	2.7	3.6	4.7
FEDERALLY FUNDED	1.2	1.7	1.8

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT, 1984

tions between AT&T and the U.S. Department of Justice. In November of 1974, the U.S. Justice Department filed suit alleging that AT&T attempted to prevent the connection of equipment and facilities. In 1981, AT&T agreed to divest itself of all facilities used to provide local telephone service beginning on January 1, 1984. Through the Consent Decree of 1982 AT&T now consists of Bell Laboratories, Western Electric Company, AT&T communications (intrastate, interstate, and international long distance), AT&T International (overseas sales), and AT&T Information Systems (customer equipment and enhanced services).

By the terms of its a divestiture, AT&T will continue to sell and lease new customer equipment in competition with the Bell Operating Companies (BOC). The BOC can offer customer equipment from the manufacturer of their choice, but may not engage in the manufacturing of communications equipment. As a result, competition in the communications equipment industry will rise, especially among telephone equipment suppliers both in the U.S. and abroad.

Increased competition in the communications equipment industry will accommodate a rapidly changing technological environment. With many of the large independent telephone companies expanding their services to include cellular radio, fiber optics, satellite services, digital electronic mail systems, and other data communications, the demand for equipment to utilize these services will also increase.

Telephone and telegraph equipment (SIC 3661) is not the only segment of the communications equipment industry to be impacted by the changing technological environment. Radio and television communication equipment (SIC 3662) accounts for 73% of 1983 shipments for the entire communications equipment industry. Steady growth is expected due to the strong, continuing demand for military electronics equipment, and for existing and newly introduced equipment with civilian application. Many communications, semi-

conductor and computer companies are combining their technologies through joint ventures, investments, licensing and other arrangements, in order to meet the demands of a highly competitive environment. This trend toward consolidation may result in a decline in the number of companies in the communications equipment industry.

Table 3-5 outlines the four dominant factors which constrain the communications equipment industry. The industry is affected by the U.S. Department of Justice rulings and FCC rulings and regulations ranging from deregulations of the telecommunications equipment industry to frequency band use. Some of these rulings have influenced growth of the industry (e.g., Consent Decree of 1982), while others have constrained it (e.g., satellite spacing requirements). The U.S. government accounted for more than 50% of the radio and television communication equipment industry's shipments in 1983. If military spending is decreased, this could adversely affect the growth of the communication equipment industry, particularly the radio and television communications equipment segment.

Competitive Trade Issues Affecting the Industry

Table 3-6 summarizes export and import statistics for telephone and telegraph communications equipment and radio and broadcast communications equipment. The U.S. trade in telephone and telegraph equipment showed a deficit in 1983 for the first time since 1974. Imports grew from $0.5 billion in 1981 to $1.1 billion in 1983, while exports increased by only $0.1 billion. This deficit is partly due to the limited access of U.S. manufacturers to foreign government controlled telephone and telegraph markets.

Japan is the leading country of origin for U.S. telephone and telegraph imports. More than 40% of all Japanese telephone and telegraph exports are sent to the U.S. The second leading exporter of telephone and telegraph equipment to the U.S. is Canada, accounting for approximately 17% of total imports.

TABLE 3-5

CONSTRAINT PROFILE OF THE
COMMUNICATIONS INDUSTRY (SIC 36)

GOVERNMENT INTERACTION	NUMEROUS INTERVENTIONS SUCH AS THE COMMUNICATIONS ACT OF 1934, THE CONSENT DECREE OF 1956, AND THE CONSENT DECREE OF 1982 HAVE AFFECTED THE TELEPHONE AND TELEGRAPH EQUIPMENT INDUSTRY AND CHANGED THE COMPETITIVE POSITION OF THE INDUSTRY.
GOVERNMENT REGULATION	NUMEROUS REGULATION BY THE FCC RESTRAIN BOTH THE TELEPHONE AND TELEGRAPH AND THE RADIO AND TELEVISION COMMUNICATION EQUIPMENT INDUSTRY, e.g., TWO-WAY RADIO LICENSES, SATELLITE SPACING REQUIREMENT, FREQUENCY RULINGS, ETC.
OWNERSHIP STRUCTURE	MAINLY LARGE FOR TELEPHONE AND TELEGRAPH; SOME WHAT FRAGMENTED FOR RADIO AND TELEVISION COMMUNICATION AND EQUIPMENT
FISCAL/MONETARY POLICY	DEPENDENT UPON MILITARY AND DEFENSE SPENDING BY THE U.S. GOVERNMENT. MORE THAN 37% OF THE 1983 COMMUNICATION EQUIPMENT SHIPMENTS WERE PURCHASED BY THE U.S. GOVERNMENT.

TABLE 3-6

COMPETITIVE POSTURE OF THE
COMMUNICATIONS EQUIPMENT INDUSTRY (SIC 366)

TRADE (BILLION $)	1972	1977	1979	1981	1983	1984 EST.
TELEPHONE AND TELEGRAPH EQUIPMENT (SIC 3661)						
EXPORTS (CURRENT $)	0.08	0.3	0.4	0.7	0.8	1.0
IMPORTS (CURRENT $)	0.09	0.1	0.3	0.5	1.1	1.4
EXPORT/SHIPMENTS RATIO	0.02	0.04	0.05	0.05	0.07	0.07
IMPORT/NEW SUPPLY RATIO	0.02	0.02	0.03	0.04	0.09	0.08
RADIO AND TELEVISION EQUIPMENT (SIC 3662)						
EXPORTS (CURRENT $)	0.6	1.4	1.8	2.3	2.5	2.6
IMPORTS (CURRENT $)	0.2	1.2	0.9	1.7	2.0	2.1
EXPORT/SHIPMENTS RATIO	0.07	0.1	0.1	0.09	0.07	0.05
IMPORT/NEW SUPPLY RATIO	0.03	0.08	0.05	0.06	0.06	0.04

U.S. exports of telephone and telegraph equipment increased by 12.5% from $0.7 billion in 1981 to $0.8 billion in 1983. The compound annual growth rate of exports between 1972 and 1983 was 24.3%. The leading markets for U.S. exports of telephone and telegraph equipment are the Far East, Europe, Latin America, and the Middle East.

The Consent Decree of 1982 between AT&T and the U.S. Justice Department emphasized deregulation and competition, which has resulted in an open U.S. telecommunications market. Many foreign firms now compete in the U.S. telecommunications market, while U.S. firms have made a limited impact on the overseas market, because telephone equipment procurement is under the authority of governmental or semigovernmental agencies in many foreign countries. The U.S. is trying to improve access for U.S. telecommunication firms to the government-procurement and customer-connect markets in Japan, the United Kingdom, and Canada through continuing discussions with the governments of these countries.

Table 3-7 compares the exports of leading countries for 1977 and 1982. During 1977-82, the U.S. held the second highest share of total exports and the second highest export growth rate. In 1982, Japan was the leading exporter of telecommunications equipment in the world with nearly 20% of the world total. The other leading exporters in 1982 were the U.S. with 16.6% of the world total, F.R. Germany with 15.8%, and Sweden with 15.6%.

Canada had the highest export growth rate in 1982, at nearly 38%. The average export growth rate during the 1977-82 period for the 10 principal competitor nations was approximately 16%. Japan, Canada, the U.S., France and Sweden all experienced growth rates greater than the 10 nation average.

Between 1977 and 1982 the imports of telephone communications equipment within the ten principal competitor nations grew at 18% annually. The U.S. experienced an annual import growth

TABLE 3-7

COMPARISON OF LEADING COUNTRY EXPORTS
OF TELEPHONE AND TELEGRAPH APPARATUS

COUNTRY	VALUE OF EXPORTS ($ MILLION)		EXPORT GROWTH RATE 1977-82	SHARE OF TOTAL 1982 EXPORTS
	1977	1982		
JAPAN	321	992	25.3	19.9
U.S.	**257**	**829**	**26.4**	**16.6**
F.R. GERMANY	524	788	8.5	15.8
SWEDEN	369	778	16.1	15.6
CANADA	78	385	37.6	7.7
FRANCE	139	355	20.6	7.1
U.K.	214	250	3.2	5.0
NETHERLANDS	213	241	2.5	4.8
BELGIUM, LUXEMBERG	202	213	1.1	4.3
ITALY	81	160	14.6	3.2
TOTAL	**2,398**	**4,991**	**15.8**	**100.0**

SOURCE: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK

rate of 37% during this period, while the growth rate for F.R. Germany was less than 3% and the Netherlands experienced an average annual decline greater than 1%.

With the British and Canadian Governments partially opening their customer equipment markets to both domestic and foreign suppliers, the U.S. may be able to increase its exports. Customer equipment sales in Canada and the United Kingdom may eventually lead to direct sales of higher value equipment, such as central office switching equipment, to the telephone authorities in these nations.

Exports for the U.S. radio and television communication equipment industry grew by 8.6% from 1981 to 1983. The compound annual rate of growth between 1972 and 1983 for radio and television communications exports was 13.7%. Canada received 9% of the total exports, the United Kingdom-9%, Japan-7%, F.R. Germany-7%, Mexico-5% and Saudi Arabia-5%.

U.S. imports increased by 1.7% from 1981 to 1982, but remained unchanged from 1982 to 1983. Approximately 43% of all imports are from Japan, while Mexico contributed 14%, Taiwan 9%, Canada 7% and Malaysia 5%. Imports amounted to less than 6% of new supplies in 1983. The low level of imports does not threaten the U.S. radio and television equipment industry.

Between 1972 and 1983 imports exceeded exports only once, during 1976, which was caused by the demand for CB radios. Imports and exports in the radio and television communications equipment industry are clearly maintaining a favorable balance of trade.

Productivity in the Communications Equipment Industry

The data in Table 3-3, taken from unpublished BLS data, indicate that labor productivity (output per employee hour) in

the communications equipment industry has been increasing. The average annual percent change in labor productivity between 1960 and 1981 was 3.4; it reached 4.2% between 1960 and 1967 and 4.1% between 1960 and 1967, 4.2%; and 4.1% between 1967 and 1981.

Role of Technology in Long-Term Strategic Outlook

The communications equipment industry has historically been active in the development of technology. New technological advances in the telephone and telegraph subdivision include: digital switches, fiber optics, satellite communication, mobile telephones and cordless telephones. An estimated 4,600 electronic switches replaced electromechanical switches between 1976 and 1983. More than 2,400 of those were time-division digital switches which combine digital signals from several telephones and transmit them over the same pair of wires. In 1984, approximately 55% of the short distance metropolitan transmission facilities were digital and 90% will be digital by 1990. The changeover to digital switching will not only provide greater flexibility (e.g., advance calling, national number calling and call screening) and a wide range of services for the user, but will also produce a larger market for telephone and telegraph equipment (e.g., electronic phones with added features, teleconferencing equipment, etc.)

A most significant technology of this industry is fiber optics, whose growth has been fostered by the development of low-cost, graded-index fibers. In 1982, approximately 170,000 kilometers of optical waveguide were installed worldwide, a number which increased to about 270,000 in 1983. In the U.S., 776 miles of fiber optic network went into service on the Washington-New York corridor in 1983. Other planned networks in the U.S. include 950 miles south and west of Chicago and a 633 mile system in California.

By the end of the century, fiber optics are expected to replace satellites for all focus of communications, except for those covering very long distances. The growth of this fiber optics technology is at the same time enhancing the growth of the entire video communications and telecommunications industries.

Satellite communications are currently the primary agent of competition in the U.S. telecommunications industry, according to market analysts. They are now responsible for 60% of the world's intercontinental telecommunications, and the U.S. domestic satellite market is experiencing a compound annual growth rate of approximately 35%. Between 1983 and 1992, 200 satellites will be launched into orbit. In the future, the interfacing of satellites and computers will result in new technological developments, products, and services.

The telephone and telegraph division of the communications industry is projected to increase in the future due to several factors:

- an increase in the construction of private homes which will result in an increased demand for main stations and equipment at central office and subscriber locations;

- conversion to digital switches which will accelerate the diffusion of other technologies such as full-motion video (teleconferencing), creating in turn a market for new equipment and services;

- the installation of fiber optic cable which will lower the cost of long distance calls and stimulate the development of new, innovative equipment;

- the demand of business communication needs which will accelerate new technological developments that integrate computer and telecommunications equipment.

This growth of the telephone and telegraph industry may be hindered to some degree by the recent divestiture of AT&T. However, while competitiveness increase among telephone equipment manufacturers, these manufacturers will be constrained to develop equipment that is compatible with AT&T systems.

The growth potential of the electronic systems and equipment division of the communications industry is affected by:

- demand for electronic systems by the U.S. military,
- demand for consumer products,
- demand for business communications products, and
- demand for high-technology communication products.

More than half of all electronic system and equipment shipments are to the U.S. military. This can be viewed as either a strength or a weakness of this industry, depending on the military's budget and constraints placed on military spending by the U.S. Congress. The demand for consumer products (burglar alarm systems, citizens band radios, automatic garage door openers, etc.) and business communications products depends upon the state of the U.S. economy; when the economy is in a recessed state, purchases by consumers and business decline.

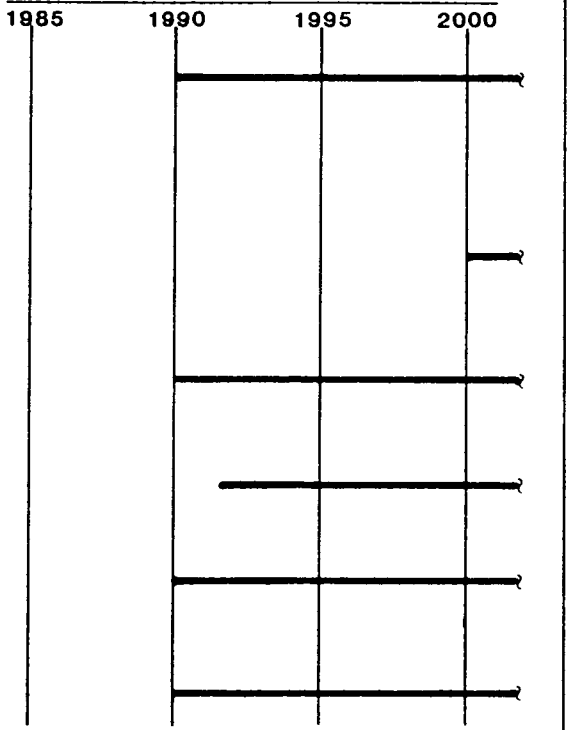
The technologies currently entering and reportedly expected to enter the communications industry in the near and medium-term are summarized in Table 3-8. The introduction of these technologies should stabilize the U.S. posture in the communications industry and encourage the development of new equipment.

Advances in fiber optic technology are continuing at a very rapid rate; specifically, the transmission rates of the new cables are increasing. In 1979, the first commercial fiber

TABLE 3-8

MAJOR TECHNOLOGY CHANGES IN COMMUNICATION EQUIPMENT

TECHNOLOGY	DESCRIPTION
ELECTRONIC SWITCHING SYSTEMS (ESS)	HIGH-SPEED, COMPUTER-BASED SWITCHING EQUIPMENT MONITORS PERFORMANCE PROVIDES ADVANCE DIALING CAPABILITIES AND CALL-HANDLING CAPABILITES.
TRANSMISSION INNOVATIONS	
• MILLIMETER WAVEGUIDE	LONG DISTANCE TRANSMISSION BY SIGNAL-CARRYING RADIO WAVES CARRIED THROUGH UNDERGROUND TUBES.
• FIBER OPTIC CABLES	VERY HIGH CAPACITY TRANSMISSION USING GLASS FIBER CABLES COMBINED WITH SEMICONDUCTOR LIGHT SOURCES.
SATELLITE COMMUNICATIONS	USE OF SATELLITES TO TRANSMIT SIGNALS BETWEEN DISTANT EARTH STATIONS.
DIGITAL TRANSMISSION	TRANSMISSION OF ELECTRICAL PULSES.
COMPUTER APPLICATION	USE OF STORED PROGRAM CONTROL FACILITIES SWITCHING, MAINTENANCE, TESTING.



optics system carried 50,000 telephone calls simultaneously on a single cable. Now AT&T is producing fiber cables that can carry 1.8 million simultaneous telephone calls. Since cost of the fiber cables is also dropping, technological advances are not only possible with fiber cable itself but with the hardware and equipment that utilize the fiber optic network.

In summary:

- Futher achievements in fiber optic technology will revolutionize the communication industry by providing video conferencing, electronic mail, videotex, etc.

- The development of the fiber optics network will create a market for new equipment which will utilize the network.

- The increased use of computer technology in industry is placing a demand on the communications industry to accelerate new technological developments that integrate computer and telecommunications equipment.

B.3.2 ELECTRONIC COMPONENTS INDUSTRY (SIC 367)

The Electronic Industries Association defines electronic components as the "elementary parts of electronic equipment and systems." Electronic components can be devices which either control voltages or do not add to signal energy. This subdivision includes electron tubes and solid-state products.

Technological developments in the electronic component industry have far-reaching consequences. The electronic components industry, thus, influences not only radios and televisions, satellites, computers, spaceflights, defense systems, and factory automation, but also communications, employment, industrial productivity and international trade.

The historical and current profile of the electronic components subdivision is summarized in Tables 3-9 and 3-10, which highlight its business and structural profiles respectively. Table 3-9 indicates that, as expressed in constant 1972 dollars, industry shipments have increased at an average annual rate of 12.1% in eleven years, from $8.8 billion in 1972 to $31.0 billion in 1983. The 1984 forecast is for shipments of $36.3 billion (1972 $), an increase of 17% over 1983. Employment has steadily increased, rising by 54.2%, from 336,000 in 1972 to 518,000 in 1983. Labor productivity, i.e., output per employee hour, has also risen fairly steadily. A slight drop was experienced between 1973 and 1974 followed by an upward swing.

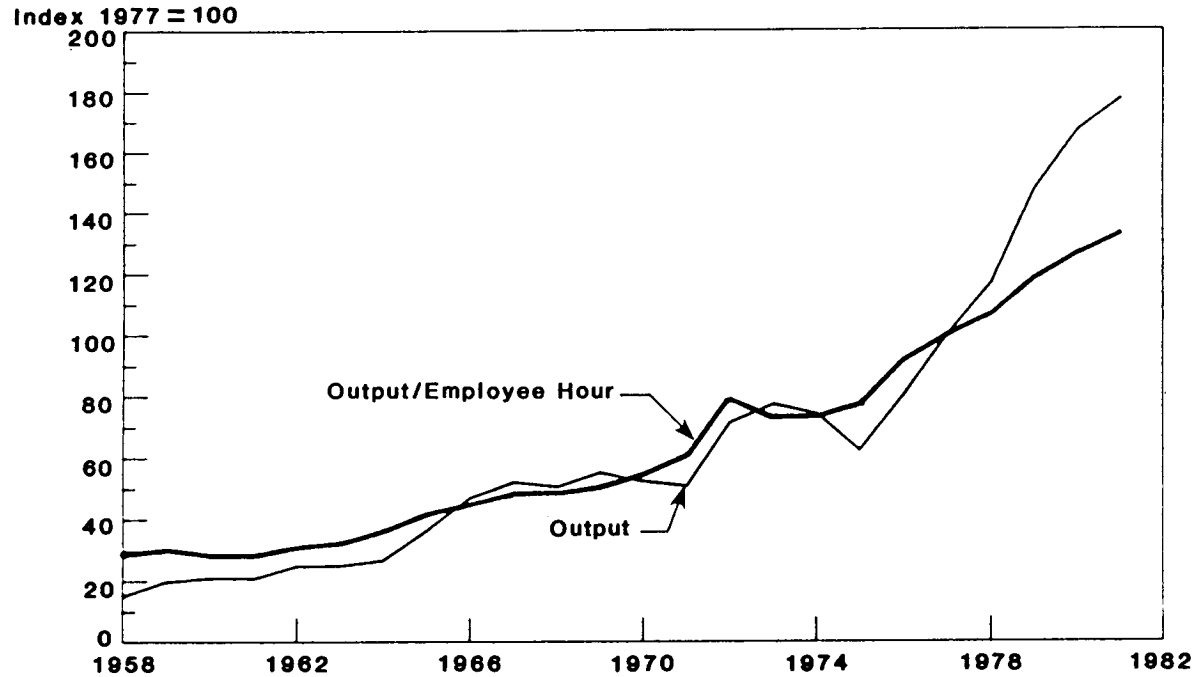
Table 3-10 shows that the electronic components industry is comprised of a large number of small firms. The cost of finished products is dominated by the cost of input materials (43%); manufacturing labor represents 16% of total costs. Other labor accounts for 14% of total production costs, which reflects the large amount of R&D expeditures.

Historically, the electronic components industry structure has encompassed both large, vertically-integrated firms, and a large number of small, entrepreneurial firms. This unique industry structure has led to a record of technological progress, evidenced by a constant flow of new products and persistant innovation in manufacturing processes. This structure has also maintained both basic research and subsequent development efforts. The large, progressive firms possess the resources and incentives to conduct long-term research projects; the smaller entrepreneurial firms have played a major role by introducing new products, and by accelerating the pace of innovation within the larger firms. However the industry currently faces problems with regard to funding research, development, and the transformation of research findings into marketable products. Therefore, many communications, semiconductor and computer firms are finding it

TABLE 3-9

BUSINESS PROFILE OF THE
ELECTRONIC COMPONENT INDUSTRY (SIC 367)

	1972	1977	1979	1981	1983	1984 EST.
SHIPMENTS (BILLION $)						
CURRENT $	8.8	15.4	20.7	30.4	36.7	42.3
1972 $	8.8	13.8	20.1	25.4	31.0	36.3
TOTAL EMPLOYMENT						
THOUSANDS	336	374	468	504	518	534



Source: Unpublished BLS Data

	1979	1981	1983
NET PROFIT MARGIN, % OF SALES	5.3	3.8	3.8
INCOME TAX RATE, %	43.0	39.6	36.0
VALUE OF PLANT, 1976, CURRENT $, BILLION			5.2

NEW CAPITAL EXPENDITURES, CURRENT $, BILLION	1977	1981
	0.8	2.5

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984
U.S. DOL/BLS

TABLE 3-10

STRUCTURAL PROFILE OF THE
ELECTRONIC COMPONENT INDUSTRY SIC (367)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	2,784
INTERMEDIATE (20-1000)	1,620
LARGE (>1000)	52
TOTAL	4,456
(4,019 COMPANIES)	

LEADING FIRMS (1983)

NAME	DOMESTICALLY GENERATED SALES ($ MILLION)
TEXAS INSTRUMENTS	1419.7
INTEL	1121.9
MOTOROLA	1056.8
NAT'L SEMICONDUCTOR	786.8
ADVANCED MICRO DEVICES	570.0
VARIAN ASSOCIATES	469.8
ROLM	368.1

	MFG. LABOR	OTHER LABOR	MATERIAL	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	16%	14%	40%	1%	29%

	1977	1979	1981
R&D EXPENDITURES, 1977 $, BILLION	0.8	1.2	1.7

PREVALENT MODE OF PROCESSING: BATCH PROCESSING

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984

advantageous to combine their technologies through joint ventures, investments, licensing, and other arrangements. This present trend within the industry towards consolidation may result in a structural change within the next decade.

Among the institutional factors which influence/constrain the electronics components industry, six stand out. As shown in Table 3-11, the industry is strongly affected by R&D costs and the availability of investment capital. The average R&D to sales ratio for all U.S. manufacturing firms is 2%; in contrast, the average research intensity ratio for electronic equipment industries is greater than 5%, and the ratio for integrated circuit manufactures ranges between 8 and 10%. This high R&D factor is due in part to the fact that many advanced electronics products have a lifetime span of only five years because of technological

TABLE 3-11

CONSTRAINT PROFILE OF THE
ELECTRONIC COMPONENT INDUSTRY (SIC 367)

RESEARCH AND DEVELOPMENT	HIGHLY RESEARCH INTENSIVE RATIO OF R&D TO SALES EXCEEDS 50%. R&D COSTS HAVE RISEN RAPIDLY MAKING IT DIFFICULT TO FINANCE LONG-TERM R&D.
AVAILABILITY OF INVESTMENT CAPITAL	SCARE CAPITAL INTENSITY INCREASING. LARGE INVESTMENT IN PRODUCTION CAPACITY REQUIRED. UNCERTAINTY ABOUT MARKET SHARES AND PROFIT MARGINS DETER INVESTORS.
AVAILABILITY OF ENGINEERS	SCARCE SUPPLY.
AVAILABILITY OF SKILLED WORKERS	SCARCE SUPPLY.
FISCAL-MONETARY POLICY	CONSUMER PRODUCT SALES ADVERSELY AFFECTED BY HIGH INTEREST RATES.
MARKET DEMAND PATTERN	HIGHLY CYCLICAL, DEPENDENT ON USER INDUSTRIES BUSINESS CYCLE AND CONSUMER DEMAND AND SPENDING.

obsolescence. This rapidly changing technology within the electronics industry calls for a continuing high rate of capital formation. Capital requirements have increased across all segments of the electronics industry with the most dramatic increase occurring in within the semiconductor industry. In 1977, the ratio of new investments to value of shipments for the semiconductor industry was 7.7%. That percentage rose to 15.2% in 1980. The increased complexity of necessary production and test equipment has made integrated circuit production capacity extremely costly. Both technological developments and intense competition to increase product performance-price ratios have resulted in a dramatic increase in the capital-output for the semiconductor industry. In the 1960s, $1 of capital equipment generated nearly $10 of sales. In 1984, the ratio of capital to new sales is approximately one-to-one. By 1990, $1 of new capital investment may generate only $0.50 of new sales.

The lack available of skilled workers (technicians, drafters, field service repairman, laboratory aides) and engineers also threatens the competitive prospects of the electronics industry. Companies do not have the luxury of picking and choosing these personnel and, in many instances, need to move individuals laterally to meet industry needs, which results in individuals working in disciplines in which they may lack formal training.

The U.S. economy also constrains the electronic components industry. With high interest rates and/or with the U.S. in a recessionary period, consumers and businesses have a tendency to defer or reduce spending on consumer and business electronic products.

Integrated circuits, with their increased capabilities and lower costs are largely replacing electron tubes. In 1980, 26% of electronic component factory sales were of integrated circuits. Since the number of such semiconductor applications have

been multiplying rapidly over the past three decades, our emphasis will be concentrated on an analysis of the semiconductor industry, primarily integrated circuits.

Competitive Trade Issues Affecting the Industry

All U.S. electronic component subdivisions are in deficit, except for electron tubes, see Table 3-12. Table 3-13 outlines the competitive trade posture for the semiconductor industry. Imports and exports of semiconductor products have risen steeply over the years. Most of the semiconductor trade consists of intercorporate transfers (American companies shipping wafers offshore to be returned later in semifinished or finished form). Approximately 80% of all U.S. imports of semiconductors and related devices in recent years have been re-imports after offshore assembly by U.S. producers. At the same time, imports from Japan have grown sharply as a share of total imports. In 1977, U.S. imports of semiconductor products originating from Japan equaled $87 million, which was 6% of total imports. In 1981, import shipments from Japan rose to $398 million which was 11% of total imports.

During the first six months of 1981 the production of semicondutors dropped by 2% in the U.S. and by 15% in Europe. However, the same period, in Japan, the domestic semiconductor production increased by 24% according to Japan's Ministry of Trade and Industry.

Japan's shipments of semiconductors to the U.S. were approximately 38% of its total worldwide exports in 1980; in 1981, this total increased to 40%. According to the Bank of America in Hong Kong, Japanese imports of U.S. semiconductors dropped by 6% from 1980 to 1981, while Japanese use of semiconductors increased by 18% during the same period.

TABLE 3-12

IMPORTS, EXPORTS, AND BALANCE OF TRADE FOR ELECTRONIC PRODUCTS BY INDUSTRY U.S.
($ MILLION)

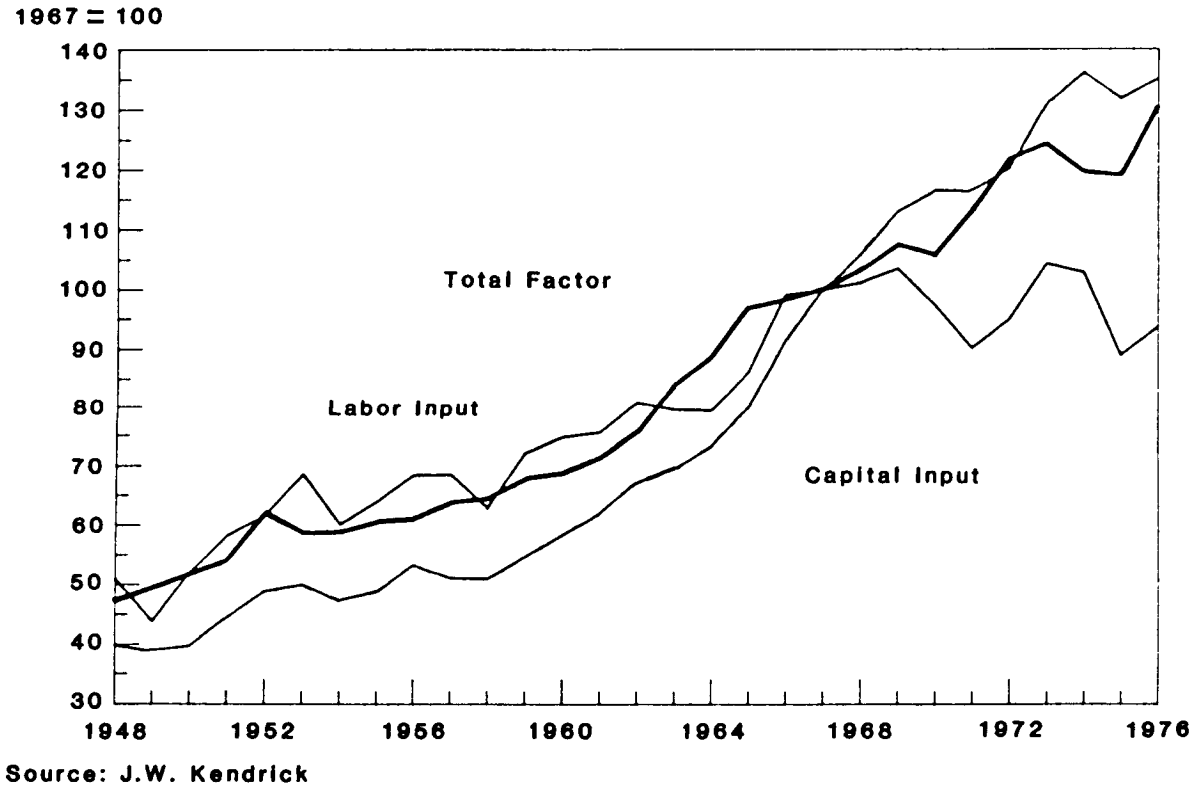
ELECTRONIC CATEGORY	1978			1980			1982		
	IMPORTS	EXPORTS	BALANCE OF TRADE	IMPORTS	EXPORTS	BALANCE OF TRADE	IMPORTS	EXPORTS	BALANCE OF TRADE
COMMUNICATION	780	1,542	762	1,036	1,872	836	1,862	2,621	759
CONSUMER ELECTRONICS	4,677	602	-4,075	4,501	814	-3,687	6,712	544	-6,168
ELECTRON TUBES	183	260	77	258	367	109	246	313	67
ELECTRONIC PARTS	1,569	1,792	223	2,355	2,564	209	3,219	1,973	-1,246
INDUSTRIAL PRODUCTS	2,450	7,320	5,870	1,935	11,692	9,757	4,540	14,959	10,419
SOLID STATE PRODUCTS	1,680	1,528	-152	2,971	2,748	-223	4,160	3,789	-371
OTHERS	323	210	-113	258	44	-214	303	78	-225
TOTAL	**10,662**	**13,254**	**2,592**	**13,314**	**20,101**	**6,787**	**21,042**	**24,277**	**-3,235**

SOURCES: ELECTRONIC INDUSTRIES ASSOCIATION: ELECTRONIC MARKET DATA BOOK, 1983

TABLE 3-13

COMPETITIVE POSTURE OF THE
SEMICONDUCTOR AND RELATED DEVICES INDUSTRY (SIC 3674)

	1972	1977	1979	1981	1983	ANNUAL GROWTH RATE 1972-83
EXPORTS, BILLION CURRENT $	0.5	1.5	2.6	3.6	4.2	22.0
IMPORTS, BILLION CURRENT $	0.3	1.3	2.4	3.6	5.0	28.1
EXPORT/SHIPMENTS RATIO	0.2	0.3	0.4	0.3	0.3	--
IMPORT/NEW SUPPLY RATIO	0.1	0.2	0.2	0.3	0.3	--



Source: J.W. Kendrick

Figure 3-1. Productivity in Electrical Machinery

U.S. semiconductor trade with Europe is more successful than with Japan. The U.S. provides Europe with 50% of its semiconductor and more than 60% of its integrated circuit demand. The U.S. initiated semiconductor production facilities in Europe in the late 1960s, which has contributed to the success of U.S. trade with Europe. However, because of the contribution of new Japanese semiconductor production facilities in Europe and the more active role of governments in assisting their local industries in establishing advanced microelectronic technology, the U.S. leadership in the semiconductor industry may be threatened by this an increase in international competition.

Productivity in the Electronic Component Industry

The graph in Table 3-9, calculated from unpublished BLS data, indicates that labor productivity (output per employee hour) in the electronic industry has been steadily increasing, expect for a slowdown during the 1973-74 recessionary period. Between 1960 and 1981 productivity grew at an average annual rate of 7.6%; between 1960 and 1967--8.0%; between 1967 and 1981--7.5%; and between 1974 and 1981--8.84%. The slight drop in productivity between 1967 and 1981 reflects the 1973-74 recessionary period when productivity only grew by 0.3%. Between 1974 and 1981 productivity grew at an average annual rate of 8.8%. It therefore appears that productivity will continue to increase within this industry.

Capital productivity for the electrical and electronic machinery industry as a whole is shown in Figure 3-1. An investment of $1 is currently needed to produce $1 of sales. Capital investment demands are growing within the industry. Investment per hour worked, expressed in 1972 dollars, has risen at an average annual rate of 4.3% from 1960 to 1981. Capital stock per hour work was $4.80 in 1960, $7.24 in 1970 and $11.60 in 1981. Despite the technological innovations within the industry in the past two decades, the capital productivity appears to be declining.

Role of Technology in Long-Term Strategic Outlook

The U.S. semiconductor industry has been highlighted by three phases during its 30 year evolution:

Phase 1: Began with the establishment of semiconductor divisions in major electronic tube industries in the 1950s. This development was encouraged by: the sponsorshp of the U.S. military, a high payment for quality, and liberal technological policies.

Phase 2: Began with the development of the integrated circuit (IC) during the 1970s. The development of the ICs caused a reduction in unit costs and dependence on military sponsoring, created entry opportunities for new entrants (merchant producers), assessed new opportunities for product differentiation, and led to a decline in the concentration of IC shipment, see Table 3-14.

TABLE 3-14

CONCENTRATION OF U.S. INTEGRATED CIRCUIT SHIPMENTS

	PERCENT OF TOTAL SHIPMENTS			
NUMBER OF COMPANIES	1965	1972	1978	1982
4 LARGEST COMPANIES	69	53	49	47
8 LARGEST COMPANIES	91	67	70	64
20 LARGEST COMPANIES	99	94	90	84
50 LARGEST COMPANIES	100	100	100	100

SOURCE: NAC: THE COMPETITIVE STATUS OF THE U.S. ELECTRONICS INDUSTRY.

Phase 3: Began with the development of large-scale and very large-scale integration (LSI and VLSI) in the early 1970s. This development caused a reduction in the rate of new entrants, an increase in mergers and acquisitions, an increased cost of capital equipment and R&D, and encouraged systems manufacturers to integrate backwards. Furthermore, the weakness of the U.S. dollar and stock market in the 1970s encouraged acquisitions by foreign firms. Recently, new companies specializing in the design and/or production of custom ICs have entered the semiconductor industry.

European and Japanese producers are generally involved in vertically integrated electronic equipment companies. The advantages of a vertically integrated structure are:

- the close interaction between component and systems division;
- the availability of capital from internal company funds.

Conversely, the U.S. semiconductor industry demonstrates a large independent merchant structure, whose advantages are:

- the merchant's ability to achieve low-cost volume production by standardizing designs in line with customer needs;
- the role of merchant producers in accelerating the pace of technological advance;
- the ability of captive producers to rely on merchant supplies for peaks in their demand;

- the promotion of a strong IC production equipment industry.

The future strength of the U.S. semiconductor industry will rely, in part, on the recognition of the interdependence between component suppliers and systems manufacturers, which will increase cooperative initiatives among computer, communications, and semiconductor firms.

The strength of the U.S. semiconductor industry is, however, threatened by the rising competiveness of the Japanese semiconductor industry. The Japanese joint government/industry VLSI research program, its favorable financial environment, its protected trade and investment policies, and its dominant position in consumer electronics have all been instrumental in the success of its semiconductor industry.

To establish a competitive advantage in electronics it is necessary to establish superior technology. Table 3-15 outlines the new technologies currently being developed in the electrical and electronic equipment industry.

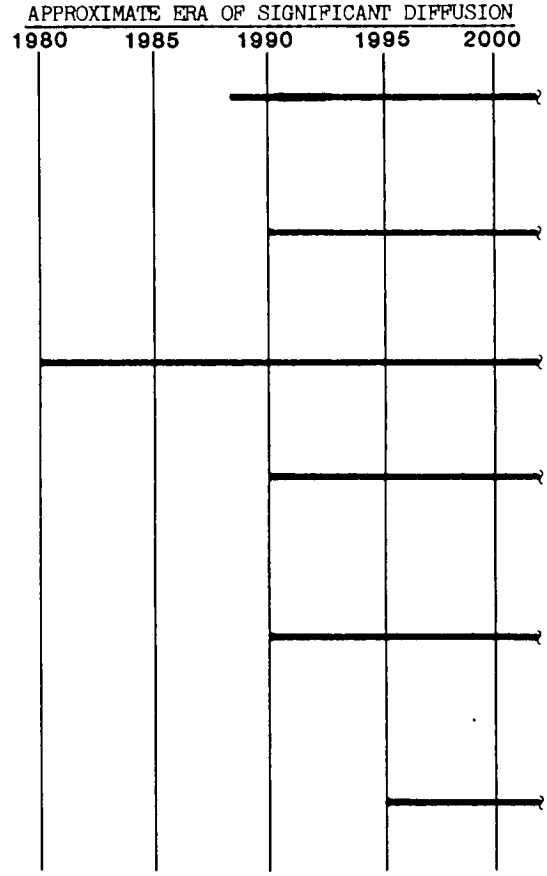
Although there are no "leap frog" technologies which appear to be developing, there are two major groupings of technologies. One major grouping of the technologies listed in Table 3-15 is better process technology. Lower manufacturing costs permit lower selling prices which result in a more competitve product. Alternatively, higher profits may be possible which can assist in finance futher R&D and/or capital improvements.

The other major grouping of technological advances is the superior product technologies which contribute to the competitive advantage since U.S. manufactures will be able to offer products that foreign firms cannot design or build.

TABLE 3-15

MAJOR TECHNOLOGY CHANGES IN
ELECTRICAL AND ELECTRONIC EQUIPMENT

TECHNOLOGY	DESCRIPTION
EQUIPMENT TO DESIGN AND FABRICATE SEMICONDUCTORS AND RELATED DEVICES.	USE OF COMPUTERS AND VIDEO DISPLAYS TO LAY OUT COMPLEX INTEGRATED CIRCUITS.
INCREASED AUTOMATION IN ASSEMBLY-LINE OPERATIONS	COMPUTER-CONTROLLED AUTOMATIC SEQUENCING AND INSERTING EQUIPMENT FOR ELECTRONIC COMPONENTS.
NUMERICALLY CONTROLLED MACHINE TOOLS	USED TO PRODUCE A WIDE RANGE OF PRODUCTS USUALLY MANUFACTURED IN SMALL QUANTITIES.
MICROSTRUCTURAL AND SUBMICROSTRUCTURAL SIZES OF SEMICONDUCTORS	INTEGRATED CIRCUIT CHIPS WITH GATE DIMENSIONS OF 0.1 MICROMETERS.
GALLIUM ARSENIDE ICs	USE OF GALLIUMARSENIDE INSTEAD OF SILICON IN IC CHIPS TO INCREASE COMPUTATIONAL SPEEDS BY A FACTOR OF 10 TO 100 AND REDUCE POWER CONSUMED.
JOSEPHSON JUNCTION	MADE FROM SUPERCONDUCTING MATERIALS; THESE OFFER THE POSSIBILITY OF LOGICAL GATES WITH VERY HIGH SWITCHING SPEEDS, HENCE VERY FAST COMPUTERS.



In summary, the semiconductor industry is a sunrise industry. The demand for semiconductors is increasing not only for computers but also for consumer electronics and household appliances which utilize "computer brains." Future U.S. leadership in the semiconductor industry will be conditioned by four factors:

1) The ability of the U.S. to remain competitive in the international trade market;

2) The increasing cooperation between systems producers and IC manufacturers in designing and producing competitive new equipment;

3) The increased strength of the U.S. consumer electronics industry;

4) The acceleration of research programs sponsored by the U.S. government and universities.

B.4 "FOOD AND KINDRED PRODUCTS" (SIC 20)

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SOURCES: U.S. DOC/BOC:

Statistical Abstract of the U.S., 1984;
Census of Manufactures, 1977;
Annual Survey of Manufactures, 1981

U.S. DOC/BIE:

1984 U.S. Industrial Outlook

EOP/DMB:

Standard Industrial Classification Manual, 1972

U.S. DOL/BLS

Standard and Poor Stock Market Encyclopedia, 1984

Value-Line Investment Survey, 1984

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B.4 "FOOD AND KINDRED PRODUCTS" (SIC 20)

The food and kindred products subsector, SIC 20, whose value added accounted for 9.8% of the manufacturing sector's contribution to GDP in 1980, comprises the fourth largest manufacturing industry. The subsector is characterized by:

- A moderate degree of fragmentation. Out of a total of approximately 26,700 establishments, 15,600 employed less than 20 persons (1977).

- A labor productivity of $27,496 per employee or $14.32 per employee hour (1980, 1972 $), ranking this subsector fourth among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 2.4%/year from 1972 to 1980 ranks this subsector third. The labor productivity for the comparable Japanese subsector was $10,955 per employee year of $5.71 per employee hour (1980, 1972 $), ranking this subsector twelfth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 4.8%/year from 1972 to 1980, ranking this subsector fourteenth.

- An average capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $17,765 in total assets per worker, ranking seventh in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $2,108 per employee (1980, 1972 $), ranking eighth in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment was 0.93 (1981).

- An average R&D program. For the subsector as a whole, R&D expenditures amounted to $0.35 billion (1980, 1972 $), ranking this subsector ninth among the 20 manufacturing subsectors. R&D expenditures were equivalent to 0.8% of the value added by the subsector in 1980.

Table 4-1 shows the major products produced by each subdivision of the food and kindred product subsector, with their share of the subsector's contribution to GDP in 1980 ranked in descending order. Table 4-2 summarizes the principal economic measures of these subdivisions.

The food and kindred products subsector comprises all of the manufacturers and processors who convert basic raw food materials into the many forms in which they are distributed to the consumer. The business and structural profiles of this subsector are summarized in Tables 4-3 and 4-4. Table 4-3 shows that, expressed in constant 1972 dollars, subsector shipments have increased 18% in eleven years, from $115 billion in 1972 to $136 billion in 1983. Employment has been relatively stable, with 1.51 million persons employed in 1981, which is slightly less than the 1.57 million persons employed in 1972. Labor productivity, i.e., output per employee hour, reached a plateau between 1977-1979 and rose approximately 6% between 1979 and 1981.

This subsector is composed primarily of establishments that are small (less than 20 employees) or medium (20 to 1,000 employees) in size (Table 4-4). Out of nearly 27,000 establishments (21,000 companies), 59% are small and 41% are medium in size, while only 0.4% (99 establishments) are large (greater than 1,000 employees). Companies include canners, freezers, meat and poultry packers, bakers, brewers and soft drink bottlers, and producers of ice cream and other dairy products. They range in size from small local concerns producing a single product to large corporations producing a multitude of products for both national and international distribution.

TABLE 4-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE FOOD AND KINDRED PRODUCTS INDUSTRY (SIC 20) AND CONTRIBUTION TO SUBSECTOR IN 1980

SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
208	**BEVERAGES** MALT AND MALT BEVERAGES; WINES, BRANDY, AND BRANDY SPIRITS; DISTILLED, RECTIFIED, AND BLENDED LIQUORS; BOTTLED AND CANNED SOFT DRINKS AND CARBONATED WATERS; FLAVORING EXTRACTS AND SYRUPS	18.0
201	**MEAT PRODUCTS** MEAT FROM PACKING PLANTS; SAUSAGES AND OTHER PREPARED MEAT PRODUCTS; POULTRY AND EGG PROCESSED PRODUCTS	13.3
203	**PRESERVED FRUITS AND VEGETABLES** CANNED FRUITS, VEGETABLES, PRESERVES, JAMS AND JELLIES; DRIED AND DEHYDRATED FRUITS, VEGETABLES, AND SOUP MIXES; PICKLED FRUIT AND VEGETABLES, VEGETABLE SAUCES AND SEASONINGS, AND SALAD DRESSINGS; FROZEN FRUITS, FRUIT JUICES AND VEGETABLES; OTHER CANNED AND FROZEN FOOD PRODUCTS	12.7
204	**GRAIN MILL PRODUCTS** FLOUR AND OTHER GRAIN MILL PRODUCTS; CEREAL BREAKFAST FOODS; RICE PRODUCTS; BLENDED AND PREPARED FLOUR; WET CORN MILLED PRODUCTS; DOG, CAT, AND OTHER PET FOOD; MISCELLANEOUS ANIMAL FEED	12.1
205	**BAKERY PRODUCTS** BREAD AND PERISHABLE BAKERY PRODUCTS; COOKIES, CRACKERS AND OTHER DRY BAKERY PRODUCTS	12.0
209	**MISCELLANEOUS FOOD PRODUCTS** CANNED, CURED, FRESH AND FROZEN FISH AND SEAFOODS; ROASTED COFFEE; MANUFACTURED ICE; MACARONI, SPAGHETTI, VERMICELLI, AND NOODLES; OTHER FOOD PRODUCTS SUCH AS GROUND SPICES, PEANUT BUTTER, AND POTATO AND OTHER CHIPS	10.4
202	**DAIRY PRODUCTS** CREAMERY BUTTER; NATURAL AND PROCESSED CHEESE; CONDENSED AND EVAPORATED MILK; ICE CREAM AND FROZEN DESSERTS; FLUID MILK	9.9
206	**SUGAR AND CONFECTIONERY PRODUCTS** BEET AND CANE SUGAR; CANDY AND OTHER CONFECTIONERY PRODUCTS; CHEWING GUM	7.9
207	**FATS AND OILS** COTTONSEED, SOYBEAN, CORN, AND OTHER VEGETABLE OIL; ANIMAL AND MARINE FATS AND OILS; SHORTENING, TABLE OILS, MARGARINE AND OTHER EDIBLE FATS AND OILS	3.7
20	ALL FOOD PRODUCTS	100.0

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1984
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972.

TABLE 4-2

SUBDIVISIONS AND CHARACTERIZATION OF THE FOOD AND KINDRED PRODUCTS SUBSECTOR (SIC 20) DURING 1980, in 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	NUMBER OF EMPLOYEES (1,000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL FOOD AND KINDRED	100	1538.8	26,656	15,614	3,805	17,765	2,108	27,496
MEAT PRODUCTS (201)	13.3	324.8	4,534	2,818	767	8,885	1,121	17,287
DAIRY PRODUCTS (202)	9.9	149.3	3,731	2,113	444	16,542	2,016	28,068
PRESERVED FRUITS & VEGETABLES (203)	12.7	233.9	2,379	1,116	618	15,344	1,654	22,872
GRAIN MILL PRODUCTS (204)	12.1	113.9	3,043	1,967	201	31,538	3,537	44,939
BAKERY PRODUCTS (205)	12.0	229.6	3,386	2,097	636	9,410	969	22,008
SUGAR & CONFECTIONERY (206)	7.9	96.9	1,198	679	251	24,360	2,525	34,206
FATS & OILS (207)	3.7	42.5	869	411	111	37,436	4,112	37,225
BEVERAGES (208)	18.0	198.8	3,104	1,414	440	32,178	4,269	38,647
MISC. FOOD PROD. (209)	10.4	149.1	4,412	2,999	337	15,335	2,002	29,539

[a] 1977

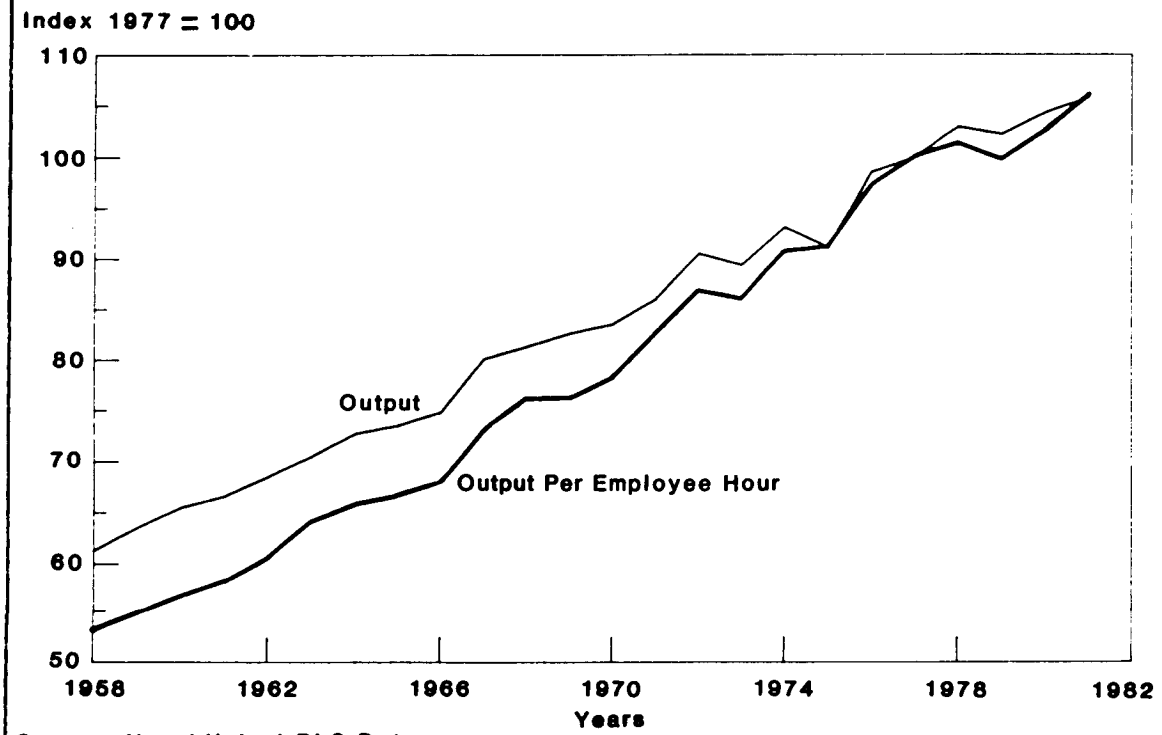
SOURCE: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981

TABLE 4-3

BUSINESS PROFILE OF THE

FOOD AND KINDRED PRODUCTS SUBSECTOR (SIC 20)

SHIPMENTS (BILLION $)	1972	1977	1979	1981	1983
CURRENT	115.1	193.1	236.0	272.1	286.3
1972 $	115.1	137.9	144.4	139.5	136.3
TOTAL EMPLOYMENT (THOUSANDS)	1,569	1,520	1,558	1,511	--



Source: Unpublished BLS Data

VALUE OF PLANT, 1977, CURRENT $, BILLION 35.1

NEW CAPITAL EXPENDITURES,	1977	1981
CURRENT $, BILLION	4.2	6.0

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOS: CENSUS OF MANUFACTURES, 1977
U.S. DOL/BLS
VALUE-LINE INVESTMENT SURVEY, 1984

TABLE 4-4

STRUCTURAL PROFILE OF THE
FOOD AND KINDRED PRODUCTS SUBSECTOR (SIC 20)

ESTABLISHMENTS (1977)
(CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	15,614
INTERMEDIATE (20-1000)	10,943
LARGE (>1000)	99
TOTAL	26,656
(20,616 COMPANIES)	

LEADING FIRMS (1983)

NAME	FOOD SALES FROM DOMESTIC PRODUCTION ($ BILLIONS)
GENERAL FOODS CORP	7.7
DART AND KRAFT, INC.	6.7
COCA-COLA CO.	6.6
ANHEUSER-BUSCH CO.,INC.	6.0
BEATRICE FOODS CO.	5.6
PEPSICO, INC.	5.3
ARCHER DANIELS MIDLAND CO.	4.3
H.J. HEINZ CO.	4.0
NABISCO BRANDS, INC.	4.0

	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	6%	4%	70%	1%	19%

R&D EXPENDITURES	1972	1977
CURRENT $, MILLION	259	395

	1978	1980
IMPORTS, BILLION $	15	17
EXPORTS, BILLION $	29	41

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984
STANDARD AND POORS STOCK MARKET ENCYCLOPEDIA, 1984

There are 500 public companies and 1,000 private companies and co-ops with revenues above $10 million in the industry; 200 of these companies have sales in excess of $300 million. The public companies with the largest dollar amount of food sales in 1983 are listed in Table 4-4.

Shown also in Table 4-4, the cost of the finished product is dominated by the cost of input materials (70%); manufacturing labor represents only 6% of the costs. In 1977 approximately $400 million was spent on R&D which is equivalent to only 0.2% of shipments. Exports exceed imports; the dollar value of exports was nearly 2.5 times the dollar value of imports in 1980.

The dominant constraints affecting this subsector are outlined in Table 4-5. At present, the subsector is almost totally dependent on the U.S. agriculture sector for its supply. In addition, government regulation, transportation costs, and fiscal/monetary policy play an important role in this subsector.

Competitive Issues in the Food and Kindred Products Subsector

Competition in the food and kindred product subsector is based primarily on marketing and cost controls; there is very little proprietary technology. The subsector is heavily regulated and can be characterized as stable with low growth and long-term growth tending to parallel population growth. Return on capital is average for all subsector segments. Key technologies developed within the subsector or adopted from another industry, are critical to maintain the competitive position of the food subsector.

The U.S. cost for agricultural production is the lowest in the world because of its advanced improvements in agricultural technology (primarily mechanization). Such low costs result in considerable food production. There is, therefore, an overriding need to develop markets that will absorb this food production output.

TABLE 4-5

DOMINANT CONSTRAINTS AFFECTING THE
FOOD AND KINDRED PRODUCTS SUBSECTOR (SIC 20)

AGRICULTURE	FOOD SUBSECTOR PRESENTLY ALMOST TOTALLY DEPENDENT ON SUPPLY FROM THE U.S. AGRICULTURE SECTOR
GOVERNMENT REGULATION	FOOD INDUSTRY AMONG THE MOST HEAVILY REGULATED INDUSTRIES IN THE U.S.; FOOD INSPECTED AT NEARLY EVERY STEP FOR HEALTH REASONS
TRANSPORTATION COSTS	QUICK TRANSPORTATION NECESSARY BECAUSE OF HIGH PERISHABILITY OF MANY FOOD MATERIALS
FISCAL/MONETARY POLICY	FOOD SUBSECTOR HAS HIGH CAPITAL INVESTMENT BASE, MAKING COST AND AVAILABILITY IMPORTANT

Future Technological Outlook for the U.S. Food Subsector

The U.S. food and kindred product subsector does not tend to be innovative; new technologies are developed at random and sporadically outside of the subsector and then transferred to the subsector. However, the following trends, which are expected to continue at least until the year 2010, may force the food subsector become more innovative:

- Less land available for raising animals because of expected housing demands on land,

- Consumer demand for lower priced, more nutritional, healthful foods.

Table 4-6 summarizes the technologies currently being developed and planned. They basically fall into two broad categories:

1) Advancements in food processing technologies. For example, technologies are being developed to process food more efficiently with less cost and nutrient waste; and to process food that is more healthful by removing less desirable ingredients such as cholesterol, salt, and fats.

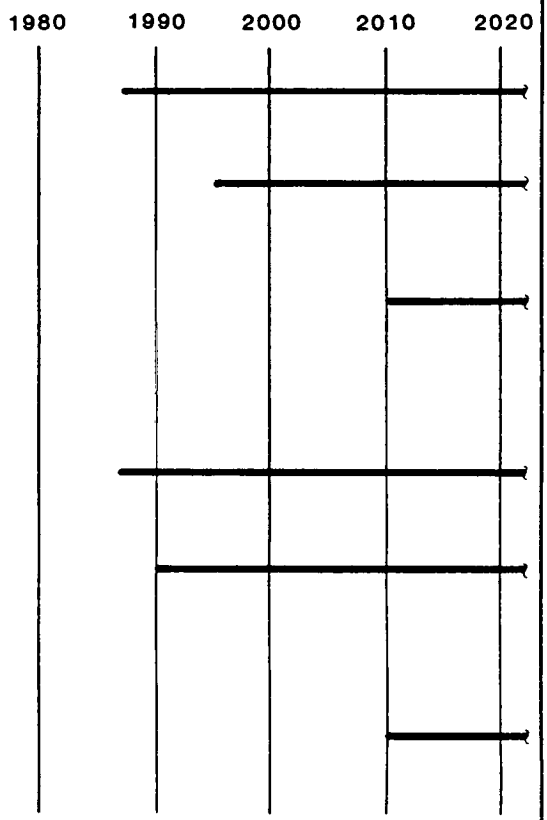
2) The artificial creation of food directly from carbon, hydrogen, oxygen, and nitrogen, without an animal or plant base.

Advancements in food processing have been evolving over time. Cryogenic and fluidized-bed freezing techniques were developed to freeze some food materials more efficiently; certain freezing and drying techniques were merged to produce freeze-drying and dehydro-freezing processes which produce food that is superior in quality. In the 1950s, there was considerable

TABLE 4-6

NEW FOOD PROCESSING TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	APPROXIMATE ERA OF SIGNIFICANT DIFFUSION
PROCESSING TECHNIQUES		
• COMPUTER CONTROL	USE OF ROBOTS TO INCREASE SANITATION, EFFICIENCY, SAFETY	
• REMOVAL OF CHOLESTEROL SALT, FATS	BIOTECHNOLOGY TECHNIQUES TO RENDER VARIOUS FOOD MATERIAL MORE NUTRITIOUS	
• IONIZING RADIATION	FOOD CAN BE PRESERVED INDEFINITELY	
FOOD SUBSTITUTIONS		
• SYNTHETIC SWEETENERS	CREATION OF CHEAPER, SAFER SWEETENERS	
• FLAVORED COLLAGENS	BIOTECHNOLOGY TECHNIQUES TO USE FLAVORED COLLAGENS TO REPLACE BEEF, LAMB, PORK, AND POSSIBLY POULTRY	
• ARTIFICIAL FOOD	FOOD CREATED CHEMICALLY FROM BASIC ELEMENTS	



interest in inoizing radiation as a preservation technique; however, interest waned because of a fear of radiation poisoning. This technique is being reconsidered because food that is preserved by ionizing radiation has an almost indefinite shelf life.

The artificial creation of food independent of plants and animals, has not yet been accomplished. The chemical synthesis of food is being researched by numerous scientists in the U.S. NASA is interested primarily because of the adaptability of synthetic food to nutrient intake in space. Most of the synthetic food that is envisioned will look and taste like conventional food, because of the psychological need of the individual for oral and textural satisfaction.

Many technologies that are being developed for agriculture, such as more efficient protein conversion in animals, with concomitant less feeding time and improved crops, will have a bearing on food composition and food costs.

Conclusion

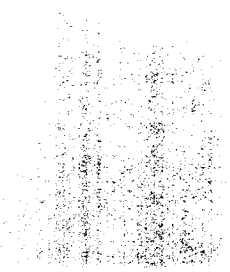
The food subsector is one of the largest manufacturing subsectors in the U.S., and is characterized by average R&D expenditures. Historically, technological innovations have been developed outside the subsector and then transferred and developed by the food subsector. The following technologies are needed for the technological advancement of the food and kindred product subsector:

- Flavoring, texturing, binding, and related technologies required to engineer artificial food or artificial ingredients of processed food.

- Processing (and/or packaging) technologies that preserve food in top condition indefinitely.

- Technologies to render food products less susceptible to nutrient losses during processing and during food preparation.

B.5 "FABRICATED METAL PRODUCTS" (SIC 34)



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Statistical Abstract of the U.S., 1982-3

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Annual Survey of Manufactures, 1981

U.S. DOC/BIE:

1984 U.S. Industrial Outlook

EOP/OMB:

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U.S. DOL/BLS:

Impact of Technology on Labor

Value-Line Investment Survey, 1984

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B.5 "FABRICATED METAL PRODUCTS" (SIC 34)

The fabricated metal products subsector (SIC 34) is the fifth largest subsector of the U.S. manufacturing sector. In 1980, the value added of this subsector contributed 7.5% to the manufacturing sector's share of GDP. The subsector is characterized by:

- A high degree of fragmentation. Out of a total of approximately 34,000 establishments, 21,000 employed less than 20 persons (1977).

- A labor productivity of $20,077 per employee year or $10.46 per employee hour (1980, 1972 $), ranking this subsector twelfth among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 1.3%/year from 1972 to 1980 ranks this subsector ninth. The labor productivity for the comparable Japanese subsector was $10,648 per employee year or $5.55 per employee hour (1980, 1972 $), ranking this subsector thirteenth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 5.0%/year from 1972 to 1980, ranking this subsector eleventh.

- A lower than average capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $11,718 in total assets per worker, ranking twelfth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $1,349 per employee (1980, 1972 $), ranking fourteenth in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment, was 0.78 (1981).

- A lower than average R&D program. For the subsector as a whole, R&D expenditures amounted to $0.31 billion (1980, 1972 $), ranking this subsector tenth among the 20 manufacturing subsectors. R&D expenditures were equivalent to 0.9% of the value added by the subsector in 1980.

- A labor intensive economic base, with a ratio of payroll to value added of 0.52 for the industry in 1977.

The fabricated metal products subsector is involved in the fabrication (i.e., machining and shaping) of unfinished ferrous and nonferrous metal including metal cans, nonpowered hand-tools, metal heating and plumbing equipment, fabricated structural metal products, screw machine products, and metal forgings and stampings. The fabricated metal products subsector uses approximately 37% of the raw iron and steel and approximatey 35% of the raw aluminum produced in the U.S. The remaining raw iron, steel, and aluminum produced in the U.S. is used by the following subsectors: Machinery Except Electrical (SIC 35), Electrical and Electronic Machinery (SIC 36), Transportation Equipment (SIC 37), and Instruments and Related Products (SIC 38).

Table 5-1 shows the major products of the subsector, ranked in descending order by each subdivision's contribution to the subsector's value added in 1980. Table 5-2 summarizes the principal subdivisions according to the 1981 Annual Survey of Manufactures.

The fabricated structural metal products subdivision (SIC 3441) accounted for 27% of the subsector's contribution to the GDP in 1980, and is primarily engaged in the manufacture of fabricated iron and steel or other metal for structural purposes. In order to assess long-term technology needs, this subdivision has been selected for detailed analysis.

TABLE 5-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE FABRICATED METAL PRODUCTS INDUSTRY (SIC 34) AND CONTRIBUTION TO SUBSECTOR IN 1980

SIC CODE	SUBDIVISION AND TYPICAL PRODUCTS	% CONTRIBUTION
344	**FABRICATED STRUCTURAL METAL PRODUCTS** BRIDGE SECTIONS, JOISTS, TOWERS, METAL BUILDING MATERIAL, STORAGE TANKS, BOILERS, NUCLEAR REACTORS, FLUES, DUCTS, LAMPPOSTS, REGISTERS, AND RAMPS.	26.9
349	**MISC. FABRICATED METAL PRODUCTS** STEEL SPRINGS, VALVES & PIPE FITTINGS, WIRE SPRINGS, BARBED WIRE, CAGES, GROCERY CARTS, GRILLS, HANGERS, SCREENS, KEY RINGS, AND TIRE CHAINS.	18.2
346	**METAL FORGINGS AND STAMPINGS** ANCHORS, HORSESHOES, WHEELS, BOTTLE CAPS, BOTTLE OPENERS, GARBAGE CANS, ICE CREAM DIPPERS, AND TEA KETTLES.	17.0
342	**CUTLERY, HAND TOOLS, HARDWARE** SCISSORS, KNIVES, FORKS, RAZORS, SWORDS, AXES, CAN OPENERS, GARDEN TOOLS, SCRAPERS, SAWS, DOOR BOLTS, HANDCUFFS, KEYS AND PADLOCKS, AND THIMBLES.	10.4
341	**METAL CANS, SHIPPING CONTAINERS** CANS, DRUMS, KEGS, AND SHIPPING PAILS.	7.7
345	**SCREW MACHINE PRODUCTS, BOLTS** BOLTS, COTTERPINS, NUTS, RIVETS, SCREW EYES, SCREWS, METAL WASHERS, AND GATE HOOKS.	6.8
347	**COATING AND ENGRAVING SERVICES** ELECTROPLATING, PLATING, POLISHING, ANODIZING & COLORING, AND COATING METAL PRODUCTS.	4.8
348	**ORDNANCE AND ACCESSORIES** AMMUNITION, SHELLS, SHOT, GUN BARRELS, GUNS, AND GUNSIGHTS.	4.7
343	**PLUMBING AND HEATING, EXCEPT ELECTRICAL** BATHROOM FIXTURES, DRINKING FOUNTAINS LAVATORIES, SPIGOTS, SPRINKLERS, WATER TRAPS, BOILERS, FURNANCES, HEATERS, AND STOVES.	3.5
34	**ALL FABRICATED METAL PRODUCTS**	100.0

SOURCE: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972

TABLE 5-2

SUBDIVISIONS AND CHARACTERIZATION OF THE FABRICATED METAL PRODUCTS INDUSTRY (SIC 34) DURING 1980, IN 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	NUMBER OF EMPLOYEES (,1000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
FABRICATED METAL PRODUCTS, ALL (34)	100	1,616.8	33,712	20,972	3,319	11,718	1,349	20,077
METAL CANS & SHIPPING CONTAINERS (341)	8	66.2	587	174	224	26,390	2,067	37,737
CUTLERY, HAND TOOLS, & GENERAL HARDWARE (342)	11	166.9	2,137	1,260	343	10,633	1,393	20,210
HEATING EQUIP. & PLUMBING FIXTURES (343)	4	58.0	1,015	674	154	8,179	946	19,516
FABRICATED STRUCTURAL METAL PROD. (344)	26	464.6	11,817	7,537	954	9,050	1,089	18,822
SCREW MACHINE PRODUCTS (345)	6	118.2	2,627	1,525	229	11,926	1,256	18,692
METAL FORGINGS & STAMPINGS (346)	20	274.5	3,715	1,840	555	17,304	2,120	20,125
COATING, ENGRAVING, AND ALLIED SERVICES (347)	4	101.6	5,095	3,722	125	8,510	875	15,387
ORDINANCE AND ACCESSORIES (348)	4	79.4	346	195	92	5,707	629	19,142
MISCELLANEOUS FABRICATED METAL PRODUCTS (349)	17	287.5	6,373	4,045	643	11,364	1,326	20,508

[a] 1977

SOURCE: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: 1981 ANNUAL SURVEY OF MANUFACTURES

B.5.1 FABRICATED STRUCTURAL METAL (SIC 3441)

The fabricated structural metal industry consists of establishments engaged in the manufacture of fabricated metal (iron, steel, and other metals) for structures such as bridges, buildings, and prefabricated components of ships, boats, and barges. The fabrication process includes cutting, bending, punching, and welding metals to form columns, joists, girders, trusses, and other specially designed structural supports. The metals used are mainly iron and steel; aluminum is the next most frequently used metal, although it accounts for only 1% of all shipments. The major markets for this industry are: commercial construction (e.g., high-rise office buildings), construction by public utilities, construction of off-shore platforms and drilling rigs, and construction of highways and bridges.

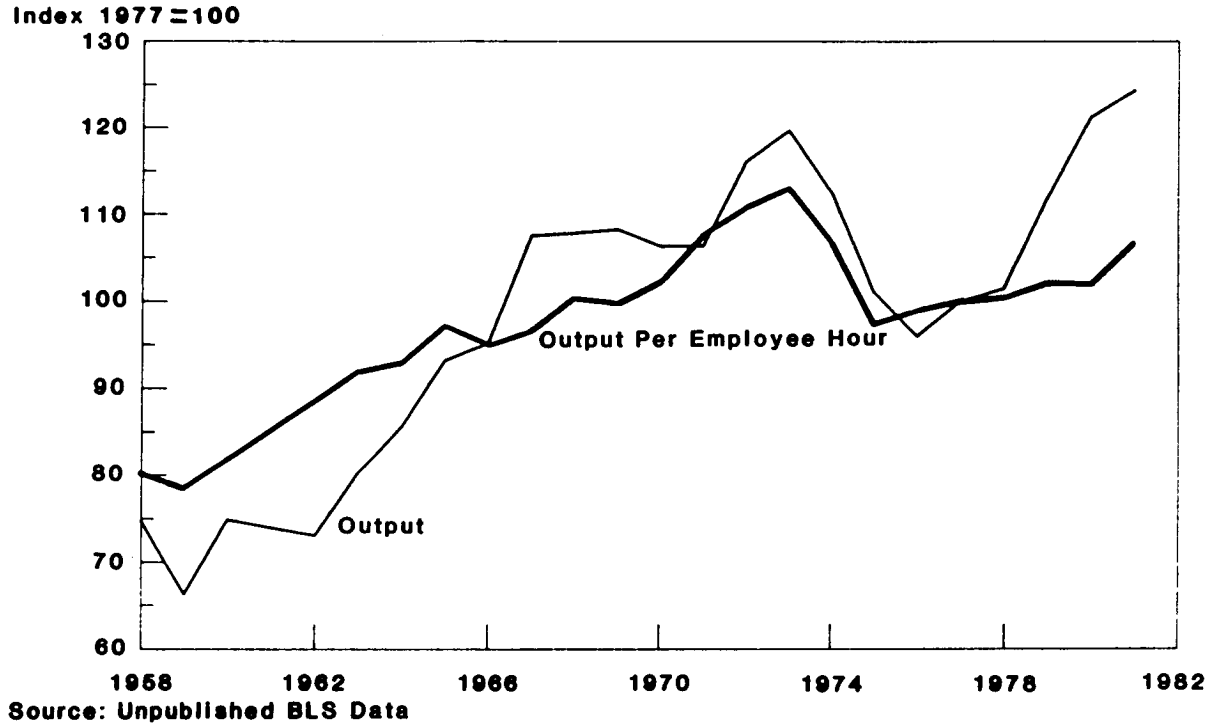
The industry's historical and current posture is summarized in Table 5-3 and 5-4, which portray the industry's business and structural profiles, respectively. Table 5-3 shows that, expressed in constant 1972 dollars, industry shipments have decreased 23% in eleven years, from $3.9 billion in 1972 to $3.0 billion in 1983. This is due in part to lagging construction in recent years and to increased imports. Employment has also declined, falling by 12% from 104,300 in 1972 to 92,000 in 1983; it reached a high of 115,000 in 1981. Probably most indicative of the situation of the fabricated metals industry is the drop in plant capacity utilization from a high of 85% in 1978 to an estimated 8 year low of 55% in 1983. This condition is largely due to lagging construction, which provides 95% of the fabricated metals market.

Table 5-4 shows that the leading firm in the fabricated structural metal industry during 1983 had sales of $395 million (1972 $). Of the subdivision's 2,462 establishments, 56% employed less than 20 persons. As shown in Table 5-4, the cost of the finished product in 1977 was dominated by the cost of materials

TABLE 5-3

BUSINESS PROFILE OF THE
FABRICATED STRUCTURAL METAL INDUSTRY (SIC 3441)

SHIPMENTS (BILLION $)	1972	1977	1979	1981	1983
CURRENT	3.9	5.5	7.4	9.1	7.3
1972 $	3.9	3.2	3.7	3.8	3.0
TOTAL EMPLOYMENT (THOUSANDS)	104.3	99.3	109.0	115.6	92.0



Source: Unpublished BLS Data

PLANT CAPACITY UTILIZATION, %	1975	1978	1980	1983 EST.
	62	85	74	55
BACKLOG, MONTHS				3-6
NEW CAPITAL EXPENDITURE, (MILLION 1972 $)		1972	1977	1981
		74.7	103	142

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977

TABLE 5-4

STRUCTURAL PROFILE OF THE
FABRICATED STRUCTURAL METAL INDUSTRY (SIC 3441)

ESTABLISHMENTS (1977)

(CATEGORIZED BY NO. OF EMPLOYEES)	
SMALL (<20)	1,388
INTERMEDIATE (20-1000)	1,071
LARGE (>1000)	3
TOTAL (2,319 COMPANIES)	2,462

LEADING FIRMS (1983)

NAME	SALES MILLION (1983 $)
ARMCO CORP.	831
U.S. STEEL CORP.	525
BETHLEHEM STEEL CORP.	490
NAT'L INTERGROUP, INC.	329

PRODUCTION COST DISTRIBUTION, 1977

MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
15%	9%	54%	1%	21%

COST OF MATERIALS, 1977

	MATERIALS CONSUMED	RESALES	FUELS CONSUMED	ELECTRICITY PURCHASED	CONTRACT WORK
% OF TOTAL COST	77.9	12.2	0.7	1.1	8.1

COST OF MATERIALS CONSUMED, (1977)

	MILL FORMS AND SHAPES	ALL OTHER
MILLION, 1972 $	1132	508
% COST	68	32

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
1984 VALUE-LINE INVESTMENT SURVEY

(54%). Labor totaled 24% of costs, with manufacturing labor contributing nearly two-thirds of the labor costs. Energy was only 1% of total costs for the finished product. Cost of materials broke down into approximately 78% for input materials (used in producing shipments) 12% for resale of materials, 1% for electricity purchased, 1% for fuels consumed and 8% for contract work.

Structural changes are occuring in the fabricated structural metals industry. In sharp contrast to the pattern toward larger plants in other manufacturing industries, the market share of large plants has declined from 22% in 1958 to 10% in 1977. This is due in part to the financial bind and subsequent plant closings of major steel producers. In 1977, single plant companies owned 93% of the plants. Most small plants compete only in an average 200 mile radius of their plants. This small local market in the industry is due to the high cost of transportation and the bulkiness of the finished product.

Among the institutional factors which constrain the industry, eight stand out as dominant. As shown in Table 5-5, the industry must meet government regulations on the quality of finished products designated for nonresidential construction use. The surface finish of materials used in bridges, schools and public utilities is particularly important, since structures can become weakened due to structural corrosion.

Because the industry ownership is so fragmented, internal R&D programs become economically unfeasible. Therefore, the industry is dependent on external sources for technological innovations.

Substantial unionization is present as 60% of industry workers are union members. As production facilities continue to migrate from the Northeast to the Southwest, a shortage of skilled workers has occurred. Because training programs for

TABLE 5-5

DOMINANT CONSTRAINTS AFFECTING THE
FABRICATED STRUCTURAL METAL INDUSTRY (SIC 3441)

GOVERNMENT REGULATION	STRICT REGULATIONS ON MATERIALS USED IN BRIDGE, HIGHWAY, SCHOOL AND FEDERAL BUILDING CONSTRUCTION.
INNOVATION	HIGHLY FRAGMENTED OWNERSHIP STRUCTURE LESSENS INTERNAL INNOVATION.
LABOR RELATIONS	60% OF PRODUCTION WORKFORCE UNIONIZED. PRODUCTION FACILITIES SHIFTING FROM NORTHEAST TO SOUTHWEST DUE TO CLOSED SHOP STATES IN NORTHEAST.
TRAINING PERIOD FOR SEMI-SKILLED OPERATORS	EXTENSIVE.
TYPE OF FINISHED PRODUCTS	MAJORITY OF ALL PRODUCTS ARE CUSTOM MADE TO SPECIFICATIONS OF CONTRACTOR.
FISCAL/MONETARY POLICY	INDUSTRY IMPACTED BY INTEREST RATE FLUCTUATIONS.
AVAILABILITY OF INVESTMENT CAPITAL	EXTREMELY LOW COMPARED TO OTHER INDUSTRIES, IN 1972 $3200/WORKER AS COMPARED TO $4200/WORKER FOR ALL MANUFACTURING.
MARKET DEMAND PATTERN	HIGHLY CYCLICAL, CLOSELY FOLLOWS THE NONRESIDENTIAL CONSTRUCTION SECTOR.

SOURCE: U.S. DOL/BLS: IMPACT OF TECHNOLOGY ON LABOR

semiskilled operators involve prolonged apprenticeship programs, the shortage is expected to continue.

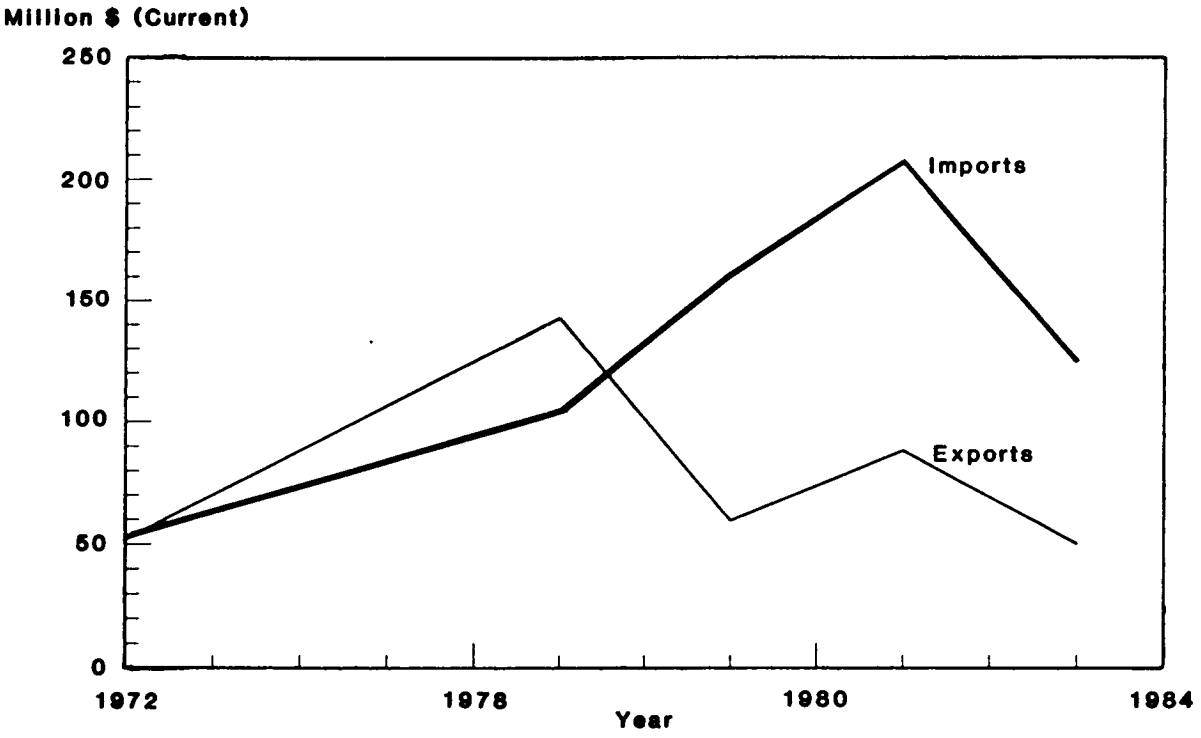
Most products must be custom made for individual contracts, making labor intensity high, due to production of a small number of different sized items. Interest rates affect the industry via loans for new construction. Investment capital is low due to the highly labor-intensive nature of the industry. From 1973 to 1980, the average expenditure per production worker for all manufacturing was nearly double that in the fabricated structural metal industry. Historically, market demand in industry sales lag behind market fluctuations in nonresidential construction (construction of office buildings, power plants, bridges, etc.) by 6 months to 1 year periods.

Competitive Issues Affecting The Fabricated Structural Metal Industry

Figure 5-1 illustrates export and import trends, and shows that imports increased while exports have declined since 1972. Imports have grown at a compounded annual rate of 8.1% in the period from 1972 to 1983, while exports have dropped 0.4%. Two percent of domestic consumption of fabricated structural metal consisted of imports in 1980, compounding the problem of low demand. Although total shipments are large in relation to total imports, the imports do provide significant competition for domestic made products in the West Coast and Mississippi River market areas. This is due to low water-freight rates keeping transportation costs low for Japanese and Korean fabricators. Further **penetration** into **U.S. markets** is **likely** if transportation costs remain low.

Productivity in the Fabricated Structural Metals Industry

The figure in Table 5-3, drawn from published BLS data, shows that labor productivity in the fabricated structural metal



Source: U.S. DOL/BOC, 1984 Industrial Outlook

Figure 5-1. Import and Export Trends in the Fabricated Structural Metal Industry

industry increased at an average annual rate of 0.9% during the period from 1960 to 1980. Average annual gains of 3.5% annually were made from 1960 to 1965 as a result of small increases in employee hours and large gains in output. Productivity only rose at a 2.2% average annual rate from 1965 to 1973. A decrease of 1.0% annually has been registered from 1973 to 1980.

The decrease in productivity after 1973 is due in part to the recession of 1974-1975. Output increases were down to 0.1% from 1973 to 1980, while employee hours were up 1.2%. This accentuates the industry's dependence on nonresidential construction, which was also down for the period. A shortage of key skilled workers (welders, machinists) was experienced. Many firms hesitated to lay off skilled workers with transferable skills (welders, machinists), even when business was slow due to fear of a lack of replacement workers when business picked up.

Some companies reported that productivity was down due to increased state and federal regulations to finish products (grind, polish, and paint) for use in bridges and public utilities. Productivity will increase as nonresidential construction demands increase in the future.

Role of Technology in Long-Term Strategic Outlook

Shipments in the fabricated structural metal industry should grow in the coming years at an average rate of 2-3%/year as nonresidential construction grows and government expenditures for mass transit increase. Shipments could reach the peak level of the 1970s ($3.9 billion during 1972) by the year 1988.

Some reduction in demand for fabricated structural metal products will be caused by reskinning of existing buildings and bridges with lighter, stronger materials, while still using the same structural skeleton (old procedure was putting up a whole new building, including the skeleton). Reskinned buildings will

be able to hold more stories, and bridges will be able to accomodate greater tonnage levels.

The fabricated structural metal industry is at the saturated point of industrial development in the U.S. due to the level of development and the advent of new materials. If foreign competition continues to increase, the industry may become sunset in the near future. There is a growing need for fabricated structural metal products in third-world countries, but the recent strength of the U.S. dollar, along with third-world financial problems, will hinder the mass export of these products overseas.

New Technologies in the Fabricated Structural Metal Industry

Table 5-6 summarizes the new technologies currently being developed and used by the industry. They fall into the following major groupings:

- More efficient material handling and positioning for fabrication. This includes beamline-CAD/CAM (the computer-controlled transportation of materials between work stations) technologies. These technologies reduce labor costs and increase quality.

- Improved welding techniques. Included here are semiautomatic welding and mechanized welding techniques; both increase welding productivity and reduce labor costs.

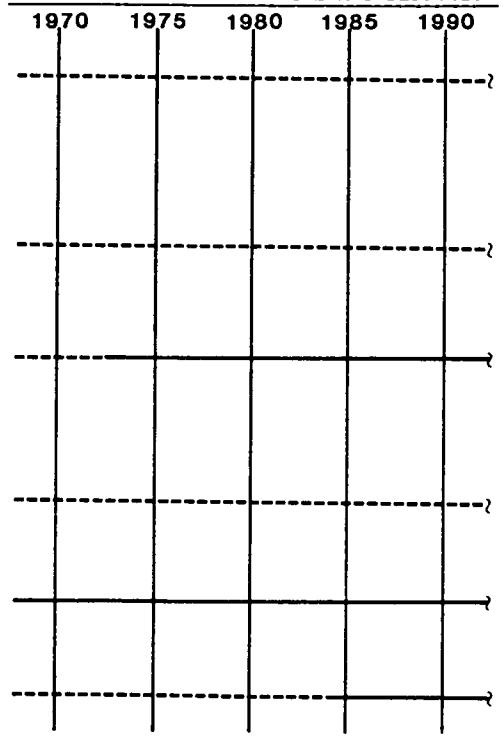
- Improved thermal platecutting. Computer numerical control (CNC), optical trace control, and cold-cutting saw developments are included. Reduces labor costs and increases output.

Beamline technology is currently the single most important technological advance in the industry. The beamline handles materials for the coordination of cutting, punching, and drilling

TABLE 5-6

NEW FABRICATED STRUCTURAL METAL TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT
BEAM LINE	TRANSPORTATION OF BEAMS BETWEEN WORK STATIONS, WITH CAD/CAM CAPABILITIES. USED IN 1/3 PLANTS CURRENTLY. CAD/CAM STILL LIMITED.	NO NEED FOR UNSKILLED LABOR, INCREASES PRODUCTIVITY.
WELDING		
• MECHANIZED	WELDING PARAMETER CONTROL PLUS CONTROL OF WELD HEAD MOVEMENT. CURRENTLY USED BY 20% OF SHOPS WITH >20 EMPLOYEES.	INCREASES WELDER DUTY CYCLE.
• SEMI-AUTOMATIC	WELDING PARAMETER CONTROL CURRENTLY USED IN 75% OF PLANTS WITH >20 WORKERS.	INCREASES WELDER DUTY CYCLE.
THERMAL PLATECUTTING		
• COMPUTER NUMERICAL CONTROL	PLASMA TORCHES CUT BY COMPUTER CONTROL--15% OF SHOPS CURRENTLY USE.	ELIMINATE TEMPLATE MAKER, SAVES TIME.
• OPTICAL TRACE CONTROL	PHOTOCELL TRACER SCANS TEMPLATE ON SPECIAL DRAFTING PAPER AND GUIDES TORCHES--WIDESPREAD USE.	LOWERS UNIT LABOR REQUIREMENT.
• COLD CUTTING SAW	CUTS AND LEAVES EDGES SQUARE AND BURR FREE--35% HAVE ADOPTED USE.	CUTTING AND REFINISHING CAN BE DONE IN 50% OF THE TIME.



----= 15% Diffusion

SOURCE: U.S. DOL/BLS

through the use of motor powered conveyors. Most are equipped with semiautomatic control, some with numerical control, and still others with computer numerical control. Diffusion of this device has slowed in recent years due to the small size of shops lacking adequate investment capital. CAD/CAM applications are also useful with beamline.

The second group is advanced welding technology. Mechanized application is the most promising technology in the group. In mechanized welding, an electrically driven wire feeder maintains the arc and feeds filler wire to the joint, and a travel device guides the welding head. A high-current welding process with higher welding speed across the joint is possible. The use of this process is just now beginning to spread, although it is not a recent development.

The third group involves the thermal platecutting of metal. CNC involves a shape-cutting machine with movement being controlled by computer commands. Operators reduce the time between cuts because positioning, preheating, and start of cut are all computer controlled. The cold-cutting saw cuts heavy structural metals such as I-beams by chipping the metal away. It runs at a slower speed than a conventional saw so it does not distort the metal with heat from friction. Finishing processes are much simpler due to the smooth edge left by the saw.

All of the above technologies are extensively used by foreign competitors, particularly Japan and Korea. A totally mechanized CAD/CAM robotic beamline, CAD/CAM mechanized welder, and CAD/CAM thermal platecutting shop is feasible in the U.S. The key to developing such automated shops would involve a restructuring of the industry; Table 5-6 shows that although new, more efficient means of production are available, many shops are not adopting them, thus continuing the lack of competitive capabilities. A shift is required from small shops lacking capital outlay funds to large ones with the ability to retool whenever tech-

nological competitiveness demands it. The reaching of this goal will be hindered by the intense fragmentation of the industry and possible union resistance to a loss of jobs.

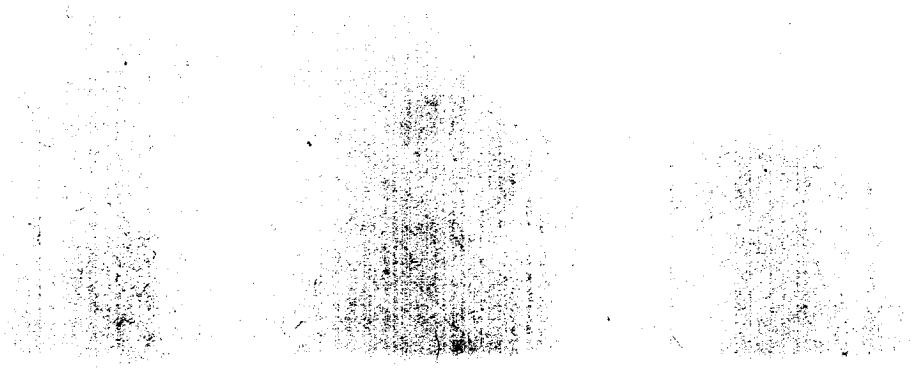
Conclusions

As mentioned previously, the fabricated structural metals industry is saturated, and it may become sunset if imports continue to increase at their current rate. There are no apparent leapfrog technologies which can be applied to the fabricated structural metal industry. Therefore, the thrust of effort should be geared toward reducing the cost of the end products.

The cost of production breaks down as follows: materials (54%), labor (24%), capital (21%), and energy (1%). Clearly, the cost of materials accounts for more than half of all production costs. This cost depends wholly on the price set by the suppliers, who are in Primary Metals (SIC 33). Refer to Section B.6 for a discussion of the primary metals subsector. Labor accounts for 24% of production costs. Use of flexible manufacturing and manufacturing cells in the fabricated structural metals industry would be ideal, due to the amount of batch manufacturing (<50 pieces) performed in the industry.

A manufacturing cell is a group of manufacturing machines which is serviced by a materials handling device, coordinated and paced by a computer, or program controller. Parts can be rapidly transferred from one machine to another, with a minimum of waiting time and inventory. A flexible manufacturing system is a group of manufacturing cells serviced by several materials handling devices, with a computer responsible for coordinating, pacing and scheduling. Refer to Section B.1 for an in-depth discussion of manufacturing cells and flexible manufacturing systems.

B.6 "PRIMARY METALS" (SIC 33)



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SOURCES:

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B.6 "PRIMARY METALS" (SIC 33)

The primary metals industry, SIC 33, is the sixth largest manufacturing subsector, whose value added accounted for 6.2% of the manufacturing sector's contribution to GDP in 1980. The subsector is characterized by:

- A moderate degree of fragmentation. Out of a total of approximately 7,000 establishments, 3,400 employed less than 20 persons (1977).

- A labor productivity of $24,349 per employee year or $12.68 per employee hour (1980, 1972 $), ranking this subsector seventh among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 2.3%/year from 1972 to 1980 ranks this subsector fourth. The labor productivity for the comparable Japanese subsector was $22,482 per employee year or $11.71 per employee hour (1980, 1972 $), ranking this subsector third among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 8.5%/year from 1972 to 1980, ranking this subsector first.

- A higher than average capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $35,216 in total assets per worker, ranking fourth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $2,835 per employee (1980, 1972 $), ranking fifth in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment, was 0.25 (1981).

- An average R&D program. For the subsector as a whole, R&D expenditures amounted to $0.41 billion (1980, 1972 $), ranking this subsector seventh among the 20 manufacturing subsectors. R&D expenditures were equivalent to 1.5% of the value added by the subsector in 1980.

Table 6-1 shows the major products of each subdivision of the primary metals sector, with their contribution to the subsector's share of the GDP in 1980 ranked in descending order. Table 6-2 summarizes the principal economic measures of these subdivisions.

The largest subdivision within the primary metals subsector, accounting for approximately 47% of the subsector's output in 1980, is the steel industry, (Sic 331), which produces iron, ferroalloys and steel produced in blast furnaces, and includes steel works and rolling and finishing mills. This industry will be discussed in detail to assess long-term technology needs.

B.6.1 THE STEEL INDUSTRY (SIC 331)

The steel industry provides unfinished processed or raw steel to other industries. There are three subgroups within this industry:

1) the integrated steel industry--those companies using coke and ore for production (in 1982, 90% of the overall steel industry);

2) the general steel industry--those companies that produce steel from scrap in electric furnaces (in 1982, 6% of the overall steel sales); and,

3) the specialty steel industry--those companies involved in tool and stainless steel production (in 1982, 4% of the overall steel industry).

TABLE 6-1

CLASSIFICATION OF MAJOR PRODUCTS OF THE PRIMARY METALS INDUSTRY (SIC 33) AND CONTRIBUTION TO GDP IN 1980

SIC CODE	SUBDIVISION DESIGNATIONS AND TYPICAL PRODUCTS	% CONTRIBUTION
331	**IRON, FERROALLOYS AND STEEL PRODUCED IN BLAST FURNACES, STEEL WORKS, AND ROLLING AND FINISHING MILLS** IRON AND STEEL PRODUCTS (PLATES, PIPE, TUBING, ETC.) AND ELECTRO-METALLURGICAL PRODUCTS.	46.9
335	**NONFERROUS METALS PRODUCED BY ROLLING, DRAWING, AND EXTRUDING** ALUMINUM, COPPER, GOLD, SILVER, TIN, ZINC, AND OTHER NONFERROUS METAL PRODUCTS.	18.2
332	**IRON AND STEEL PRODUCED IN FOUNDARIES** CAST IRON AND STEEL PRODUCTS.	14.9
333	**NONFERROUS METALS PRODUCED BY SMELTING AND REFINING** BARS, BLOCKS, INGOTS, AND OTHER FORMS OF ALUMINUM, COPPER, AND ZINC.	9.4
336	**NONFERROUS METALS PRODUCED IN FOUNDARIES** CAST ALUMINUM, BERYLLIUM, COPPER, ZINC AND OTHER NONFERROUS METAL PRODUCTS.	5.5
339	**MISCELLANEOUS PRIMARY METAL PRODUCTS** NONFERROUS NAILS, BRADS, SPIKES, METAL POWDER, FLAKES, PASTE, AND HEAT TREATING OF METAL.	2.9
334	**NONFERROUS METALS PRODUCED BY SECONDARY REFINING** ALUMINUM, BRASS, COPPER, PRECIOUS METAL, ZINC AND OTHER NONFERROUS METAL PRODUCTS PRODUCED BY SECONDARY REFINING.	2.2
33	ALL PRIMARY METALS	100.0

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION, 1972

TABLE 6-2

SUBDIVISONS AND CHARACTERIZATION OF THE PRIMARY METALS INDUSTRY (SIC 33), DURING 1980, in 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	NUMBER OF EMPLOYEES (1,000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSESTS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL PRIMARY METALS INDUSTRIES	100	1,096.1	7,375	3,393	1,734	35,216	2,835	24,349
BLAST FURNACES (331)	48	489.9	1,126	475	442	47,477	3,365	25,560
IRON & STEEL FOUNDARIES (332)	17	219.7	1,465	432	497	19,440	2,236	18,143
PRIMARY SMELTING & REFINING (333)	10	59.4	160	60	88	65,483	3,663	42,038
SECONDARY SMELTING & REFINING (334)	2	22.0	460	260	51	24,918	3,062	26,918
ROLLING, DRAWING & EXTRUDING (335)	16	184.2	1,002	291	413	27,149	2,689	26,341
NONFERROUS FOUNDRIES (CASTINGS) (336)	5	87.6	1,892	1,087	213	12,737	1,591	16,724
MISCELLANEOUS PRIMARY METAL PRODUCTS (339)	2	33.3	1,180	788	30	17,397	1,661	23,279

[a] 1977

SOURCES: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981

The subdivision's historical and current posture is summarized in Tables 6-3 and 6-4, which portray the steel industry's business and structural profiles, respectively. Table 6-3 shows that, expressed in constant 1972 dollars, industry shipments have declined 25% from 1972 ($28 billion) to 1983 ($21 billion). However, because of the recent economic recovery, the Department of Commerce projection is that shipments will rise 14% to $24 billion in 1984. Employment has steadily declined by 39%, from 543,000 in 1972 to 330,000 in 1983. Labor productivity, i.e., output per employee hour, displays a cyclical pattern; however, it was at 61 in 1982 (1977=100), the lowest level during the 28 years that the index was published.

Table 6-4 shows that there are eight firms with $800 million to $5 billion in steel sales, with the four largest companies accounting for 45% of industry shipments. The largest companies are integrated steel producers. There are a total of 903 firms with 1,165 establishments; most of the establishments (618) are intermediate in size with 20 to 1,000 employees. The cost of production is dominated by the cost of input materials (52%); but, manufacturing labor (16%) and energy (11%) are also significant cost items.

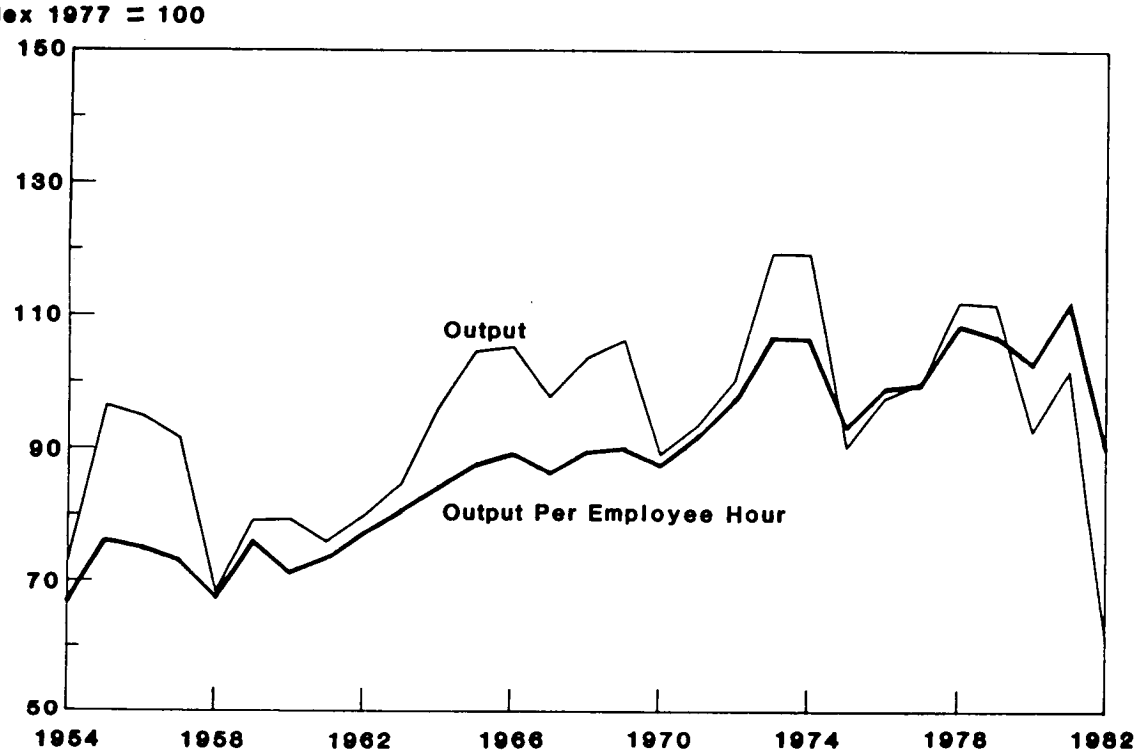
The steel industry is one of the highest users of water of any manufacturing industry (5.74 billion gallons per day). Primary wastewater treatment encompasses physical/chemical methods of treatment, including neutralization, sedimentation, flocculation, and filtration. Biological treatment, ion exchange, carbon absorption, reverse osmosis, and other chemical techniques are used to treat toxic water pollutants.

The steel industry is also one of the leading contributors to air pollution. The major air pollution control technologies include electrostatic precipitators, scrubbers, fabric filters, canopy hoods, evacuation systems, water sprays, and desulfurization units. During the 1975-1981 period, the steel industry

TABLE 6-3

BUSINESS PROFILE OF
THE STEEL INDUSTRY (SIC 331)

	1972	1977	1979	1981	1983	1984 EST.
SHIPMENTS (BILLION $)						
CURRENT $	28.1	49.7	66.0	69.0	60.4	—
1972 $	28.1	27.8	30.4	26.6	21.0	24.1
TOTAL EMPLOYMENT (THOUSANDS)	543	521	535	469	330	—



Source: Published BLS Data

PLANT CAPACITY UTILIZATION, 1983, %		60-80
NET PROFIT MARGIN AFTER TAXES, 1981, %		4.9
VALUE OF PLANT, 1976, CURRENT $ BILLION		35.2
	1977	1981
NEW CAPITAL EXPENDITURES, CURRENT $ BILLION	2.4	3.2

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOL/BLS

TABLE 6-4

STRUCTURAL PROFILE OF THE STEEL INDUSTRY (SIC 331)

ESTABLISHMENTS (1977) (CATEGORIZED BY NO. OF EMPLOYEES)

SMALL (<20)	464
INTERMEDIATE (20-1000)	618
LARGE (>1000)	83
TOTAL (905 COMPANIES)	1165

LEADING FIRMS (1982)

NAME	SALES BILLION CURRENT $	OUTPUT MILLION TONS
U.S. STEEL CORP.	5.3	12.1
BETHLEHEM STEEL CORP.	5.3	10.7
LTV CORPORATION	4.8	6.5
NATIONAL INTERGROUP	3.0	5.5
INLAND STEEL CO.	2.8	5.2
ARMCO INC.	5.4	5.1
REPUBLIC STEEL CORP.	2.7	5.1
WHEELING-PITTSBURGH STEEL CORP.	0.8	1.8

(FOUR LARGEST COMPANIES--45% OF INDUSTRY SHIPMENTS)

PRODUCTION COST DISTRIBUTION, 1977	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
	16%	5%	52%	11%	16%

R&D EXPENDITURES, $ MILLION	1972	1977	1979
CURRENT $	146	261	293
1972 $	146	187	180

ESTIMATED PLANT AGE, YEARS 8-17

AVERAGE ANNUAL POLLUTION CONTROL COSTS (MILLION 1972 $)

	1970-78	1981-90
AIR	151	668
	1972-78	1981-90
WATER	52	189

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES
VALUE-LINE INVESTMENT SURVEY, 1984
EPA: 1984 COST OF CLEAN AIR AND WATER REPORT TO CONGRESS

spent $3.4 billion on pollution control, 13% of its $26 billion capital expenditures.

The constraints present in the steel industry are outlined in Table 6-5. The industry is affected by EPA regulations mandated by the Clean Water and Clean Air acts leading to increased cost of production. Contributing to the cost of production is the high labor cost brought about by the influence of unionization. Foreign steel makers benefit at the expense of domestic firms when fiscal/monetary policies cause the U.S. dollar to rise in relation to foreign currencies.

Competitive Issues Affecting the Steel Industry

Table 6-6 shows that although steel production has declined nearly 40%, from 151 million tons in 1973 to 92 million tons in 1983, imports are at about the same level in 1983 (14.5 million tons) as they were in 1973 (15.1 million tons). During the same time period, exports have declined from 4.1 million tons in 1973 to 1.0 million in 1983.

A comparison between the steel making capabilities of Japan and the U.S. is shown in Table 6-6. In 1964, Japan's steel production was less than one-third of U.S. production and its productivity was inferior to the U.S. By 1972, however, Japan's steel production was nearly equal to the U.S., and its productivity had matched U.S. productivity levels. At the same time, hourly costs and the cost of steel material in Japan remained far lower than in the U.S. In 1980, Japan's steel production surpassed that of the U.S. by 10.9 million short tons.

Tables 6-7 and 6-8 show total and per capita production of crude steel and aluminum, respectively, by the leading producers of the free world. Comparisons were made only among free world countries because of wide gaps between production and consumption in these countries. Table 6-7 shows that free world per capita

TABLE 6-5

DOMINANT CONSTRAINTS AFFECTING
THE STEEL INDUSTRY (SIC 331)

GOVERNMENT REGULATIONS	IN 1981, $1.1 BILLION (1.8% OF SHIPMENTS) SPENT FOR AIR POLLUTION CONTROL AND $383 MILLION (0.56% OF SHIPMENTS) SPENT FOR WATER POLLUTION CONTROL. COSTS EXPECTED TO RISE 65% BY 1990.
LABOR RELATIONS	BY CURRENT AGREEMENT, COST OF LABOR IS $22.51 PER HOUR, MORE THAN DOUBLE COMPARABLE JAPANESE AND EUROPEAN STEEL WAGES. DOMESTIC STEEL WORKER PRODUCTIVITY EXCEEDED BY JAPANESE, GERMAN, AND CANADIAN STEEL INDUSTRIES AT COMPARABLE OPERATING RATES.
FISCAL/MONETARY POLICY	AT MID-1983, IMPORT STEEL PRICES WERE ESTIMATED TO BE ONE-THIRD BELOW DOMESTIC PRICES.
UTILITY (WATER) COST	AVERAGE OF 40,000 GALLONS OF WATER USED TO PRODUCE 1 TON OF FINISHED STEEL.

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
EPA: 1984 COST OF CLEAN AIR AND WATER REPORT TO CONGRESS

TABLE 6-6

COMPETITIVE POSTURE OF
THE STEEL INDUSTRY

ITEM (MILLIONS OF TONS)	1973	1978	1979	1980	1981	1982	EST. 1983
RAW STEEL PRODUCTION	151	137	136	112	121	75	92
STEEL MILL PRODUCTS	111.4	97.9	100.3	83.9	88.5	61.6	70
EXPORTS	4.1	2.4	2.8	4.1	2.9	1.8	1.0
IMPORTS	15.1	21.1	17.5	15.5	19.9	16.7	14.5
APPARENT DOMESTIC CONSUMPTION	122.5	116.6	115.0	95.2	105.4	76.4	83.5

	1964		1972		1980	
	U.S.	JAPAN	U.S.	JAPAN	U.S.	JAPAN
TOTAL OUTPUT, MILLIONS OF SHORT TONS	93	34	95	88	111.9	122.8
OUTPUT, SHORT TONS/1,000 HOURS	81	38	94	85		
TOTAL HOURS/SHORT TON	12	26	11	12		
HOURLY COST, $	4.63	0.74	7.44	2.48		
UNIT LABOR COST, $/SHORT TON	57.00	19.40	78.94	29.37		

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOL/BLS

TABLE 6-7
CRUDE STEEL PRODUCTION

	1960	1965	1970	1975	1980	COMPOUND ANNUAL RATE OF GROWTH (%) 1960-1970	COMPOUND ANNUAL RATE OF GROWTH (%) 1970-1980
TOTAL PRODUCTION (MILLION METRIC TONS)							
U.S.	90.1	119.3	119.3	105.8	101.5	2.8	-1.6
JAPAN	22.1	41.2	93.3	102.3	111.4	15.5	1.8
WESTERN EUROPE	97.7	114.0	138.0	126.7	129.6	3.5	-0.6
FREE WORLD EST.	242.7	324.6	415.6	420.8	448.6	5.5	0.8
PER CAPITA PRODUCTION (POUNDS/PERSON)							
U.S.	1099	1354	1282	1080	983	1.5	-2.6
JAPAN	518	921	1972	2021	2103	14.3	0.6
WESTERN EUROPE	896	997	1168	1040	1058	2.6	-1.0
FREE WORLD EST.	268	324	376	344	333	3.4	-1.2

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1984
U.S. CIA/DOI: HANDBOOK OF ECONOMIC STATISTICS, 1983

TABLE 6-8
PRIMARY ALUMINUM PRODUCTION

	1960	1965	1970	1975	1980	COMPOUND ANNUAL RATE OF GROWTH (%) 1960-1970	COMPOUND ANNUAL RATE OF GROWTH (%) 1970-1980
TOTAL PRODUCTION (THOUSAND METRIC TONS)							
U.S.	1827	2498	3607	3519	4654	7.0	2.6
JAPAN	133	294	733	1013	1091	18.6	4.1
WESTERN EUROPE	520	735	1040	1950	2240	7.2	8.0
FREE WORLD EST.	3680	5021	7530	9021	11872	7.4	4.7
PER CAPITA PRODUCTION							
U.S.	22.3	28.3	38.9	35.9	45.1	5.7	1.5
JAPAN	3.1	6.6	15.5	20.2	20.6	17.5	2.9
WESTERN EUROPE	4.8	6.4	8.8	16.1	18.3	6.2	7.6
FREE WORLD EST.	4.1	5.0	6.8	7.4	8.8	5.2	2.6

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1984
U.S. CIA/DOI: HANDBOOK OF ECONOMIC STATISTICS, 1983

production of crude steel decreased from 376 pounds/person in 1970 to 333 pounds/person in 1980, a compound annual decline of 1.2%/year. Table 6-8 shows that, during the same time period, free world per capita production of aluminum increased from 6.8 pounds/person in 1970 to 8.8 pounds/person in 1980, a compound annual increase of 2.6%/year. This shows that demand for steel has decreased while the demand for aluminum has increased. The substitution of aluminum (or aluminum alloys) for steel in various products (such as automobiles, ships and buildings) accounts for at least a part of this shift in preference.

Table 6-7 also shows that U.S. per capita crude steel production decreased from 1282 pounds/person in 1970 to 983 pounds/person in 1980, a compound annual decrease of 2.6%/year. The U.S. has also fallen from a position as the leader in per capita crude steel production (1099 pounds/person in 1960) among the leading free world producers (U.S., Japan, Western Europe) to being the smallest per capita producer of crude steel (983 pounds/person in 1980) among the large producers.

Long-Term Strategic Issues in the Steel Industry

In general, the technology in the steel industry is outdated. With the exception of computerization, new technologies in this industry have typically represented improvements of previous methods of production or processing.

However, in recent years, with competition from foreign sources and a fluctuating economy, the steel industry has been forced to modernize or face continually reduced profits. To increase demand and reduce expenditures, several innovations have been attempted, including the potential mergers of corporations (i.e., the proposed LTV/Republic merger); the leasing rather than purchase of equipment; the leasing of a troubled or shutdown plant from another corporation; the elimination of a product line; the expansion into new markets, or complete diversification.

Table 6-9 summarizes the technologies currently being developed and planned. The most important technological change for the steelmakers is continuous casting. This technology reduces a multi-step operation to one step and has been widely adopted by foreign countries: the diffusion in 1978 is 45% in Japan compared to only 14% in the U.S. The benefits of continuous casting include energy conservation (energy cost was 11% of shipments in 1977), increased labor productivity (labor cost 21% of shipments), lower capital cost per ton of output, increased quality of steel (fewer steps and greater automatic control), lower pollution (eliminates soaking pits and reheating furnaces), and use of more scrap steel.

Among major steel mill product categories, sheets appear most likely to suffer long-term decline, reflecting weaker demand for consumer durables, particularly automobiles. A subcategory of the sheet market, tinplate used in containers, is likely to continue to lose position as steel cans lose market share to aluminum and plastic. Other steel markets are not likely to offset the losses steel has sustained in automobiles and cans, despite accelerated defense programs and perhaps some renovation of the domestic rail system and highway bridges. On the positive side, major new substitutions for steel by competitive materials are unlikely.

Figure 6-1 outlines OTA's projected future rise in steel demand. Although other materials will be substituted for steel for some uses, steel remains the material of choice for bridges, large buildings, railroads, and primary manfacturing facilities. Part of the future demand for steel will be from the replacement of such physical structures as they wear out.

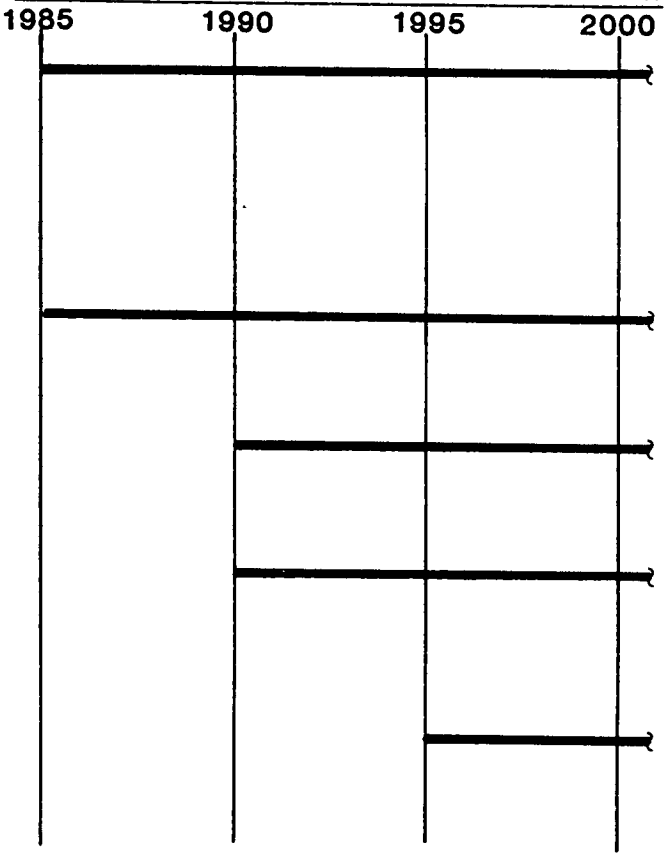
Conclusion

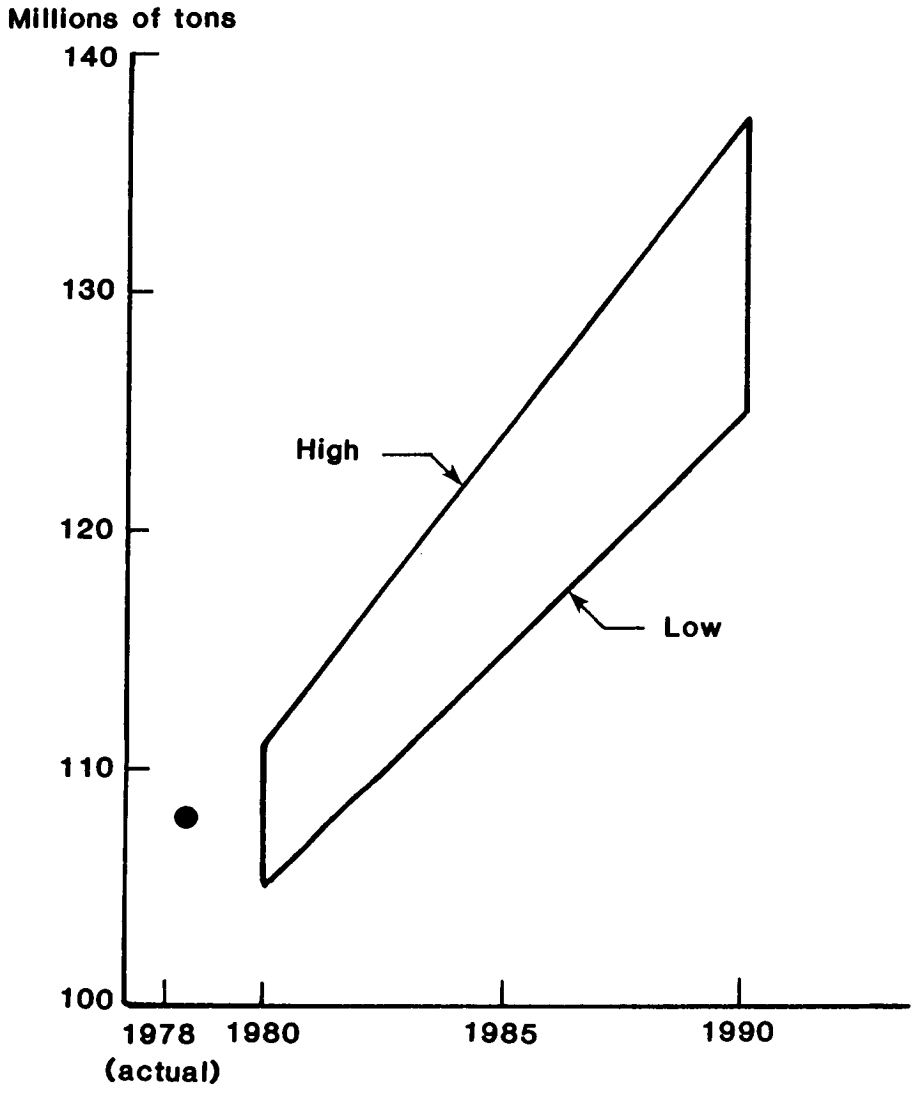
Steel continues to be the most important engineering material in the U.S. economy; thus a healthy steel industry is vital

TABLE 6-9

NEW STEEL INDUSTRY TECHNOLOGIES

TECHNOLOGY	DESCRIPTION
CONTINUOUS CASTING	MOLTEN STEEL IS POURED DIRECTLY INTO CASTER PRODUCING SEMI-FINISHED FORM. ELIMINATES INGOT-PRODUCING STEP. DIFFUSION IN 1978 14% IN U.S. VS. 45% IN JAPAN.
ELECTRIC-ARC FURNACE	STEELMAKING PROCESS USING 100% SCRAP.
COMPUTER CONTROLS	OPERATIONS CONTROLLED AUTOMATICALLY.
VACUUM DEGASSING	IMPURITIES REMOVED FROM MOLTEN STEEL, CAUSES INCREASED YIELD.
ADVANCED BASIC OXYGEN PROCESS (Q-BOP)	MORE PRODUCTIVE REFINEMENT OF THE BASIC OXYGEN PROCESS, CAUSES INCREASED YIELD (BOP USES 75% IRON AND 25% SCRAP).





[a]Demand = total consumption = domestic shipments - exports + imports.
SOURCE: Office of Technology Assessment.

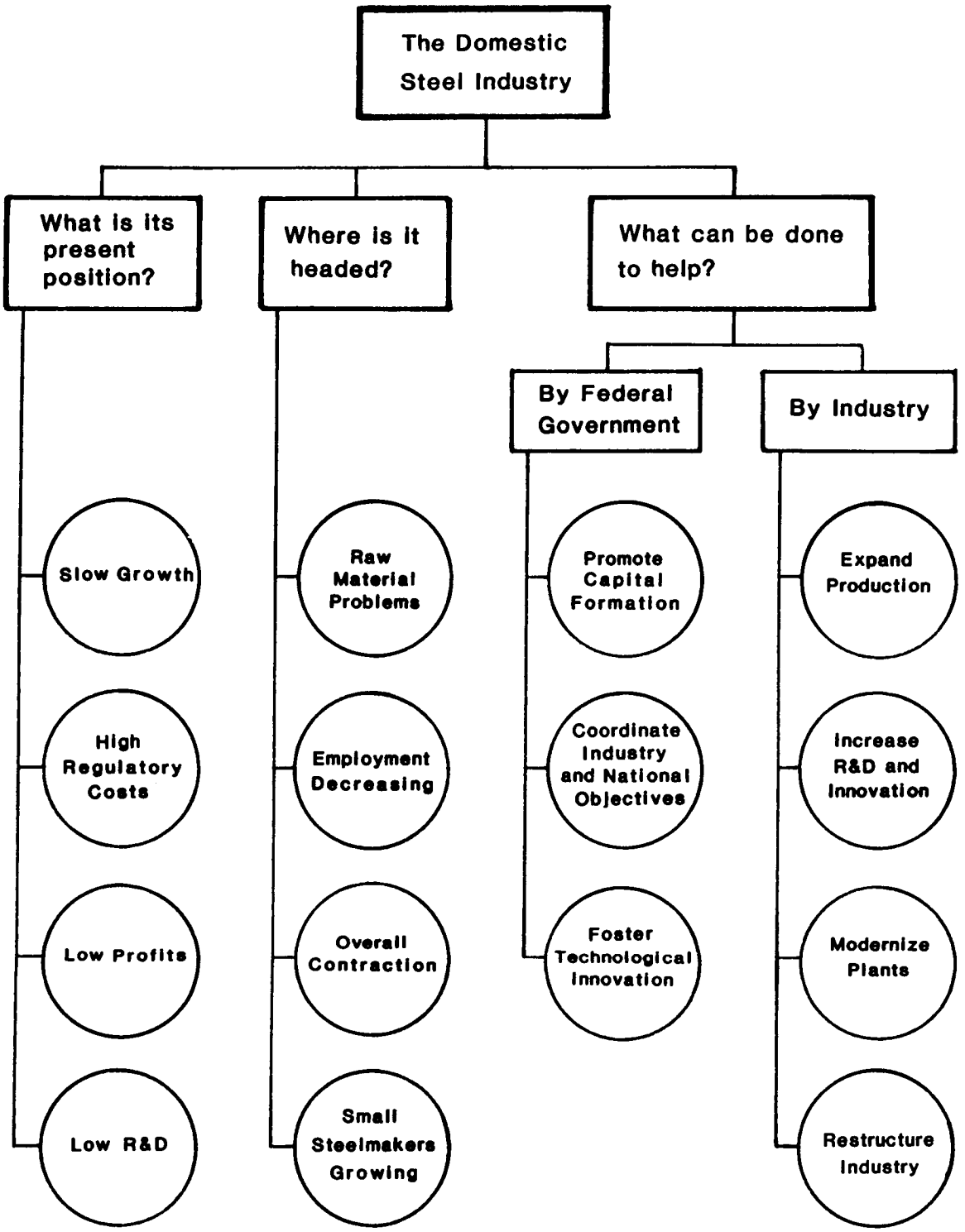
Figure 6-1. Range of Projected Domestic Demand[a] for Steel, 1980 - 1990

to the security and economic prosperity of the U.S. However, because of the significant foreign penetration into the U.S. market, the technological gap being experienced, and the high cost of labor, the U.S. steel industry can be considered in the sunset stage of industrial development.

Figure 6-2 summarizes the current position of the steel industry, where it is headed, and what can be done by the federal government and private industry to help. Specifically, the following are needed to revitalize the steel industry:

- Increased investment in R&D. The federal government needs to support basic research in steelmaking, provide incentives for steel companies to conduct R&D, and assist in pilot and demonstration projects.

- Increase in capital spending for the adoption of new technology. Steel companies need to increase their capital spending to approximately $4.3 billion (OTA estimate) in the next decade in order to modernize mills, expand capacity modestly, and increase profitability. OTA estimates that supportive federal policies are needed to generate at least 20% of steelmaker's capital spending needs.



Source: Congress of the U.S., Office of Technology Assessment

Figure 6-2. Example of Inter-Relationships Between Government and Industry